COMMUNICATION ANALYSIS
FOR THE
EXPENDABLE EXPLORER SPACECRAFT

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EXECUTIVE SUMMARY

This report provides the results of communication analysis for the baseline and enhanced performance spacecraft designs* proposed for Expendable Explorer Spacecraft (EES) series of missions, to be launched in 1998 through 2005. Five classes of orbits (Geosynchronous, Circular-28 degree inclination, Polar-90 degree inclination, Sunsynchronous-97 degree inclination, Molniya orbit) and a set of candidate instrument payloads provided by the EES Study Manager were used to formulate the basis for the EES Communication Study.

This study was performed to assess the feasibility of using Space Network or ground stations for supporting the communications, tracking and data handling of the candidate instruments that are proposed to be launched into the desired orbit.

All orbits except the geosynchronous and Moiniya orbits are capable of being supported by current TDRSS capabilities. Either Wallops or GSFC NTTF could be used as the ground station for these two exceptions. The ATDRSS system with a look angle of 77.5 degrees either side of nadir point line can easily support all five classes of orbits. It should be in place in the beginning of the EES period.

For the low Earth orbit mission (Circular-28 degree inclination, Sunsynchronous-97 degree inclination, Polar-90 degree inclination), the enhanced design spacecraft could support via TDRSS all but three of the low Earth orbit strawman instruments. One of the three could be supported as well if a longer contact period via TDRSS were to be used.

For the low Earth orbit mission (Circular-28 degree inclination, Sunsynchronous-97 degree inclination, Polar-90 degree inclination), the baseline spacecraft design could support six of the 22 low Earth orbit strawman instruments via Wallops with only minor modifications to the Wallops equipment. Nine more of the low Earth orbit strawman instruments could be supported but would require upgrades to the Wallops communications and data handling equipment. Seven of the strawman instruments cannot be handled without upgrades to Wallops' RF equipment which could be cost prohibitive. Five of these seven that cannot be supported via Wallops could be supported via TDRSS using an enhanced design.

For the high Earth orbit mission (Geosynchronous, Molniya), there were two out of three strawman instruments that can be supported by the EES designs via ATDRSS. One very high data rate instrument would require K-Band support which is beyond the EES design. Two out of three strawman instruments can be supported by the EES designs via Wallops. Again, the very high data rate instrument would require K-Band support which is beyond the EES design.

In the consideration of using ground stations for supporting the candidate instrument payloads in low inclination or polar orbits, the capabilities of the non-NASA facilities, the transportable ground station, and a dedicated equatorial ground station was examined to determine how to effectively support the EES mission. Several of these approaches appear viable and capable of supporting a wide range of potential EES instrument payloads. However, the implementation details and costs of these approaches should be studied further.

* The baseline spacecraft design provides an average data rate of 10 kbps, and uses a TDRSS-compatible transponder and omnidirectional antenna. The enhanced spacecraft design provides an average data rate of 100 kbps, and uses a TDRSS-compatible transponder and a high gain antenna.

ACRONYMS

AERO	Upper Atmosphere & Ionosphere
AEROS	Active Explorer Research Observing Satellite
AIDR	Average Instrument Data Rate
AIM	Atmosphere-Ionosphere-Magnetosphere Explorer
ARTBE	Auroral region Tethered Bolo Experiment
ATDRSS	Advanced TDRSS
AVT	Average Viewing Time
C&DH	Command and Data Handling
CCSDS	Consultative Committee for Space Data Systems
COBE	Cosmic Background Explorer
CPD	Contacts Per Day
DOD	Department of Defence
DSN	Deep Space Network
EES	Expendable Explorer Spacecraft
EIRP	Effective Isotropic Radiated Power
EMAO	Earth/Mars Aeronomy Orbiter
ERBS	Earth Radiation Budget Satellite
ESA	European Space Agency
ESSA	Electronic Switching Spherical Arrays
EUVU	Ultra-Violet and Visible Astronomy and Relativity
EXCAM	Energetic X-Ray Camera
FOV	Field of View
Gbits	Gigabits
GEO	Geosynchronous Orbit
GHz	Gigahertz
GOES	Geostationary Environmental Satellite
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
G/T	Ration of Receiver Gain to System Thermal Noise Temperature
HEASI	High Energy All Sky Imager
HECRE	High Energy Cosmic Ray Explorer
Hi-E	High Energy Astrophysics
HEO	High Earth Orbit
HXRE	Hard X-Ray Explorer
HXSIE	High Throughput X-Ray Spectroscopy and Imaging Explorer
IMAGE	Images of the Magnetosphere and Atmosphere: Global Effects
IMP-8	Interplanetary Monitoring Platform-8
IRSU	Infra-Red and Radio Astronomy
IUE	International Ultraviolet Explorer
JPL	Jet Propulsion Laboratory

ACRONYMS (Continued)

USAF	United States Air Force
VHF	Very High Frequency
WFF	Wallops Flight Facility
WPS	Wallops Island Orbital Tracking Station
WSGT	White Sands Ground Terminal
ZOE	Zone of Exclusion

1.0 INTRODUCTION

1.1 PURPOSE OF STUDY

The National Aeronautics and Space Administration (NASA) intends to launch a series of Expendable Explorer Spacecraft (EES) during the 2000's. These missions will have a range of orbits from near-Earth, to highly elliptical, to geosynchronous. Their purpose is to support experiments covering the disciplines of aeronomy, ultra-violet and visible astronomy and relativity, high energy astrophysics, infra-red and radio astronomy, magnetospheric physics, and solar physics.

The EES is a mass produced spacecraft bus that can house a variety of scientific experiments operating in a wide range of mission orbits. The desired duration of these experiments ranges from 12 to 36 months. EES spacecraft are expected to be launched approximately every 18 months over a six-year period beginning in 1999. The launch rate and desired duration implies that as many as three spacecraft may require support at one time; this number may increase if an EES remains active beyond its planned lifetime. Simultaneous support of three or more spacecraft may be required if they are being supported by the same ground station.

It is proposed to use the Delta rocket to launch these payloads. The Delta launcher will deliver payloads from 250 kg to 4000 kg to orbits ranging from near-Earth to geosynchronous, from near the equator to high inclination. The largest Delta shroud allows a payload volume up to 32.3 cubic meters. The variety of orbits and payload constraints allows some flexibility in the communications choice for each mission.

CTA, Incorporated was given a task to quantitatively analyze communication alternatives for selected orbits and candidate experiments. The benefits and costs of using either the Space Network or Ground Stations for EES communication are evaluated in the report. Both the spacecraft design and the mission support operations are considered. Key technical issues are addressed, and the most suitable approaches to EES communications are identified.

1.2 STUDY APPROACH

The approach taken was first to review the study environment and drivers. It included an examination of capabilities and constraints of existing and future Space Network (SN) and Ground Stations, review of launch vehicle performance, and analysis of proposed orbits and contact times as well as the selection of candidate instrument payloads.

Sensitivity analysis indicated that orbit geometry and data rates would drive the study results. Inputs from the EES Study Manager were used to select a class of orbits and responses to the Explorer Concept Study Program Notice [Ref. 1] were used to identify the strawman experiments and derive expected data rates.

The study then focused on the link margins and contact times using link calculations, SN capabilities including Advanced Tracking Data Relay Satellite System (ATDRSS), Ground Station capabilities, possible orbits, and possible data rates.

Analysis was then performed to decide whether the Tracking Data Relay Satellite System (TDRSS) or ground stations should be used. This analysis utilized the link margins, baseline and enhanced EES design options [Ref. 2], and the data rate requirements of the strawman experiments.

1.3 ORGANIZATION OF REPORT

Section 2 of this report contains background data on the capabilities of the existing SN and ground stations. It also describes future TDRSS and ATDRSS capabilities and discusses their possible impact on EES communications. Readers who are familiar with this information should skip to section 3.

Section 3 discusses the drivers and requirements embodied in launch vehicle performance, orbits, contact times, and strawman instrument considerations.

Section 4 evaluates the link margins when using the SN to support the EES.

Section 5 evaluates the link margins when using ground stations to support the EES.

Section 6 considers ground station and communication alternatives including non-NASA and foreign resources, transportable ground stations, and direct transmission of data to scientific investigators.

Section 7 presents overall conclusions and recommendations.

Appendix A presents the view times of several strawman instruments with various ground stations and TDRSS. These view times were extracted from computer printouts, provided by Code 554.0 in support of this study, and listed in tabular form for each of the selected strawman instruments. The average view time for Wallops was used to determine contact times that can be expected for spacecraft with similar orbits.

Appendix B is the SEAS TEAM QUICK NOTE provided by Code 554.0 that contains the maximum slant ranges to various strawman instruments from several ground stations and TDRSS. It also provides the equations used to determine those maximum slant ranges which were used for the figures in the conclusions.

Appendix C explains the link calculation used in section 5.

Appendix D explains how the data rate requirements used in the figures in the conclusions were derived.

2.0 BACKGROUND ON THE SPACE NETWORK AND NASA GROUND STATIONS

This section contains background data on the capabilities and limitations of the NASA communications resources, including TDRSS/ATDRSS and NASA ground stations. Note: readers that are knowledgeable on this subject should go on to section 3.

2.1 SPACE NETWORK CAPABILITIES

This section describes current and projected capabilities of the SN that are relevant to the support of EES. These capabilities are discussed in terms of two applicable SN systems, the S-Band Multiple Access (MA) system and the S-Band Single Access (SSA) system. The K-Band single access (KSA) service was judged not relevant to the EES concept because of expense; its capabilities are mentioned in this section but its application to EES will not be studied in the other sections. Table 2.1-1 summarizes the SN capabilities.

Signals originating on the ground and flowing through a Tracking and Data Relay Satellite (TDRS) en route to a user spacecraft are said to use the forward link, while signals originating in a user spacecraft and flowing through a TDRS en route to the ground are said to use the return link.

With a single TDRS in operation, communication with a user is feasible for approximately half of each user spacecraft orbit. Currently two TDRSs are operational. Each TDRS is placed in a geosynchronous orbit, with one axis pointed to the center of the earth. The TDRS points its antennas at the spacecraft it supports; using mechanical pointing in the case of the SSA antennas, or electrical pointing in the case of the S-Band MA antenna array. In either event, the antennas are not pointed more than approximately 20° away from the line connecting the TDRS to the center of the earth. The geometry of this limitation requires that a spacecraft in a circular orbit can not have an altitude greater than 12,000 km above the surface of the earth. For spacecraft in low Earth orbit (LEO), nearly continuous communication is expected to be feasible except in the zone of exclusion

(ZOE). The ZOE is a region over the Indian Ocean where spacecraft with orbits at altitudes lower than 1200 km are not visible to either TDRS. Spacecraft with orbits higher than 12,000 km are visible to a TDRS only a small part of the time because the spacecraft is outside of that TDRS's viewing angle for a large part of the orbit. Figure 2.1-1 shows the middle coverage zone geometry of TDRSS for user spacecraft at altitudes between 1200 km and 12,000 km. This figure also shows a no-coverage zone which is the ZOE for spacecraft with altitudes less than 1200 km. A TDRS can support spacecraft with orbits greater than 12,000 km but only when it passes through the specific coverage zone geometry for that TDRS. Figure 2.1-2 shows this TDRS upper coverage zone geometry. Figures 2.1-1 and 2.1-2 were taken from the SN Users Guide [Ref. 3].

NASA plans to have four TDRSs in orbit by 1995 and will phase out TDRSS with ATDRSS in the EES time frame, this is discussed in Section 2.1.3.

Table 2.1-1. Space Network Capabilities

Capability	MA	SSA
FORWARD LINK		
Simultaneous Users	1 per TDRS	2 per TDRS
EIRP	34 dBW	43.6 dBW
Frequency	2106.4 MHz	2025-2120 MHz
Polarization	LCP	LCP or RCP
Maximum Data Rate	10 kbps	300 kbps
Range Error	50 nsec	50 nsec
RETURN LINK		
Simultaneous Users	20 *	2 per TDRS
G/T	-1.9 dB/degK	9.2 dB/degK
Frequency	2287.5 MHz	2200-2300 MHz
Polarization	LCP	LCP or RCP
Data Channels	2	2
Data Rate	0.1-50 kbps	6 Mbps

Notes:

TDRS = Tracking and Data Relay Satellite
EIRP = Effective Isotropic Radiated Power
dBW = decibels relative to 1 Watt
MHz = megahertz
LCP = left hand circular polarization,
RCP = right hand circular polarization
nsec = nanosecond (10^{-9} sec)
G/T = receiver gain per system noise temperature
dB/degK = decibels relative to (1 degree Kelvin)$^{-1}$

* Maximum simultaneous links is a function of the TDRSS ground terminal equipment.

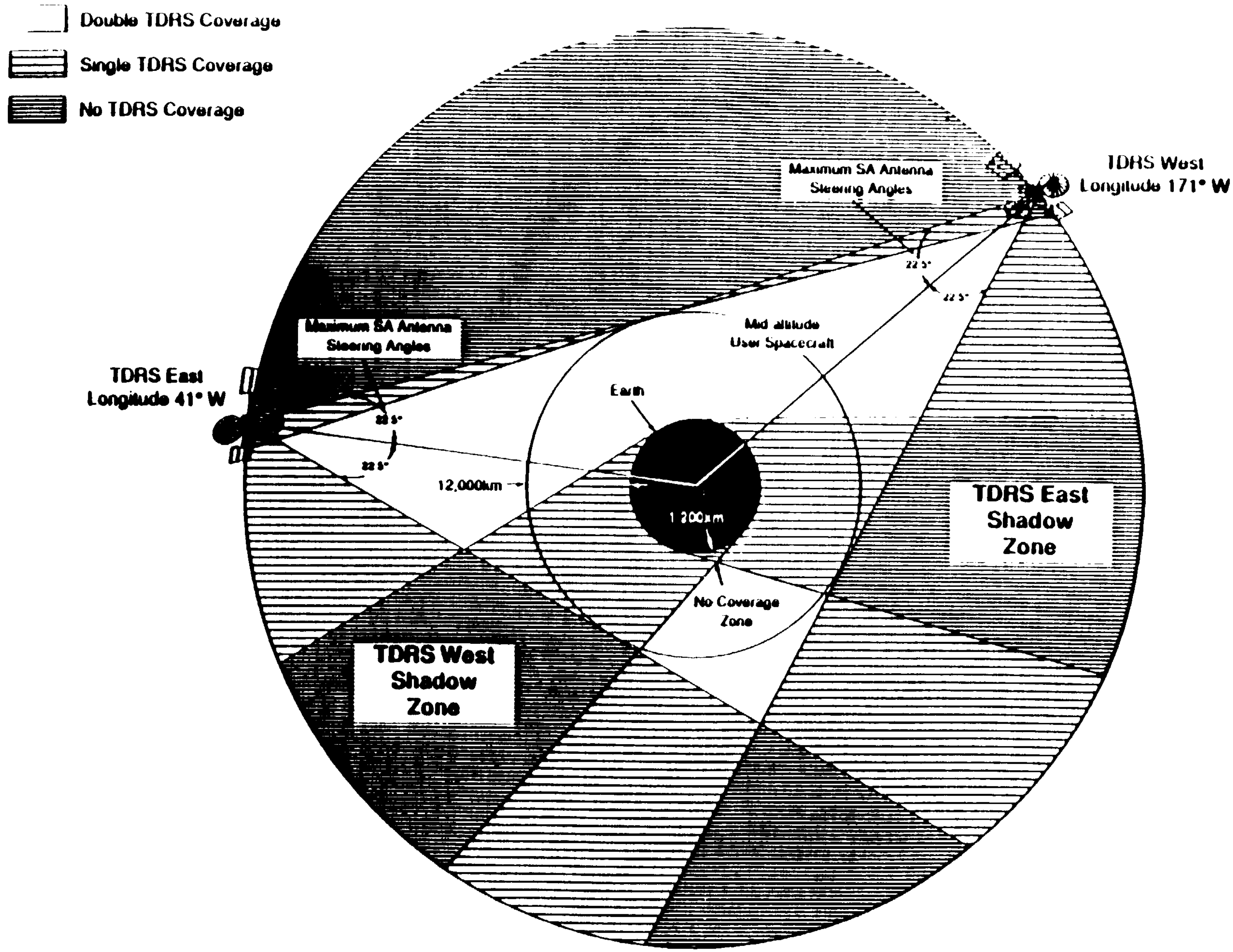

Figure 2.1-1. **TDRSS Middle Coverage Zone Geometry, User Spacecraft Altitudes from 1200 to 12,000 km**

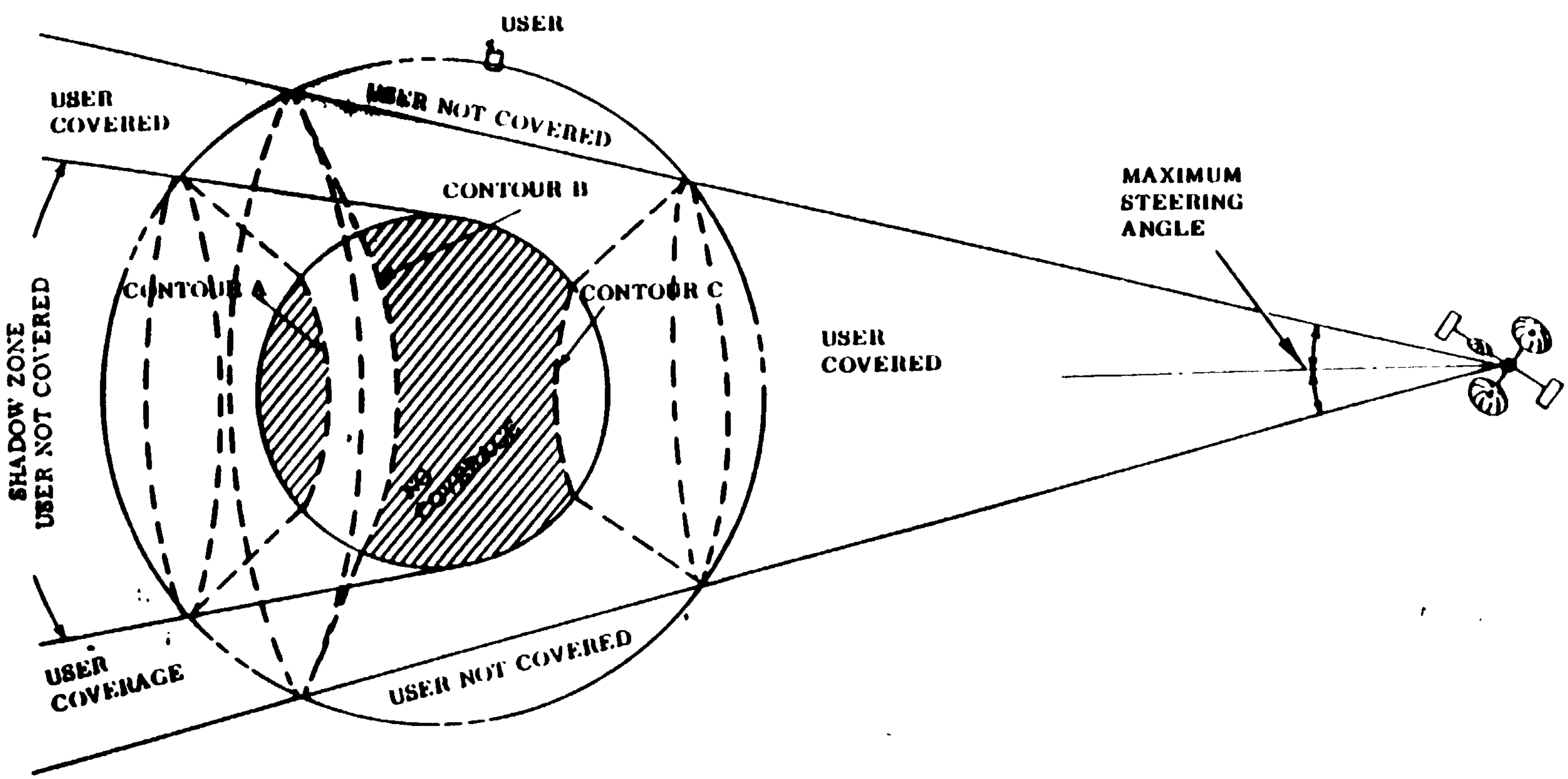

Figure 2.1-2. TDRS Upper Coverage Zone Geometry, Altitude Greater Than 12,000 km

2.1.1 Present Multiple Access (MA) System

The MA system provides bi-directional S-Band communications channels between ground facilities and multiple user spacecraft. These channels are normally used to send telemetry, command, and tracking signals.

The MA space segment on each TDRS uses a phased array of antennas to provide a single forward link data channel and up to 20 return link data channels. MA services are time-shared among users to provide essential services to as many users as possible.

The MA system permits command rates of up to 10 kilobits per second (kbps), telemetry rates of up to 50 kbps, and measurement of user range and range rate. The forward link operates at 2106 megahertz (MHz) and uses spread spectrum techniques to limit the spectral power density impinging on the ground. The return link operates at 2288 MHz and uses code division multiple access techniques to separate the signals of multiple users.

Users of the MA system must employ a transponder that meets NASA specifications. Such transponders are readily available from several vendors.

2.1.2 Present Single Access (SA) System

The SA system provides bi-directional S-Band and K-Band communication channels between ground facilities and up to two user spacecraft per TDRS. These channels are normally used to transmit high rate sensor data along with telemetry, command, and tracking signals.

Each TDRS has dual 15-foot (4.6-meter) SA antennas that can be independently pointed at separate user spacecraft. Each antenna can provide bi-directional communication with a single user with two data channels in each direction. SA services are time-shared among multiple users to provide communications for as many users as possible.

The SSA system permits command rates of up to 300 kbps, telemetry rates up to 6 Mbps, and measurement of user range and range rate. While the MA system uses fixed operating frequencies, the SSA system is tunable over a band of frequencies, 2025 to 2120 MHz for the forward link and 2200 to 2300 MHz for the return link.

The K-Band Single Access (KSA) system permits nominal command rates of up to 25 Mbps, telemetry rates up to 300 Mbps, and measurement of user range and range rate. The KSA forward link operates at 13 GHz and the return link operates at 15 GHz.

SA users face fewer compatibility requirements than MA users and have greater freedom in choosing frequencies and transmitter power levels. The SA service is therefore in demand, and must be allocated to competing missions on a priority basis. The EES missions are unlikely to receive a high priority in this evaluation and will probably find access to the SA service very restricted unless future TDRSS capabilities relax these constraints.

2.1.3 Future TDRSS Capabilities and the ATDRSS Era

In 1995, a second TDRS will be added to both the East and West satellite locations to begin the "Cluster" operation that will double the support capabilities. These TDRS will offer S-Band MA, SSA, and KSA services. Currently, a Second TDRSS Ground Terminal (STGT) is being built to support the Cluster operations.

The ATDRSS era will be from 1997 to 2012. Replacement of the TDRS with ATDRS is expected to occur over a seven year period, from 1997 to 2003 [Ref. 4]. ATDRS will provide enhanced capabilities including support for Ka-Band, data rates to 650 Mbps, and orbits to geosynchronous. Table 2.1-2 shows a baseline service comparison of TDRSS and ATDRSS [Ref. 5]. Each ATDRS will have an expanded field of view (FOV) for the SSA services. The FOV for each SSA antenna is ±22.5° east/west and ±31° north/south of the nadir point line. If the ±77.5° east/west FOV is realized then a minimum slant range to a satellite in geosynchronous orbit is approximately 15,500 km. Figure 2.1-3 shows the viewing capability of ATDRSS using a look angle of 70° either side of the nadir point line. The ±70° FOV is a conservative approach but demonstrates that ATDRSS can easily cover spacecraft out to geosynchronous. Using a ±70° FOV, the minimum slant range to a geosynchronous satellite is about 28,900 km. EES communications will need to meet TDRSS limitations in the earlier part of the mission but should be able to rely on ATDRSS capabilities during the later part of the mission time frame.

Table 2.1-2. TDRSS/ATDRSS Baseline Service Comparison

Service			TDRSS (1996)	ATDRSS (2003)	Notes
Single Access	S-Band	Forward	300 kbps	300 kbps	No change.
		Return	6 Mbps	6 Mbps	
	Ku-Band	Forward	25 Mbps	25 Mbps	No change.
		Return	300 Mbps	300 Mbps	
	Ka-Band	Forward	N/A	50 Mbps	23/26 GHz frequency band recommended.
		Return	N/A	650 Mbps	
	Number of links		8 SSA 8 KuSA	8 SSA 8 KuSA 8 KaSA	For ATDRSS, permissible combinations and simultaneous operation of S, Ku, Ka services via a single SA antenna are required.
Multiple Access		Forward	4 ea @ 10 kbps	8 ea (3 dB over TDRSS)	Anticipated SSA users ≤ 3 Mbps offloaded to ATDRSS SMA.
		Return	19 ea @ 50 kbps	20 ea @ 3 Mbps (9-10 dB over TDRSS)	
User Tracking			150 meters, 3σ	150 meters, 3σ	Improved user tracking is being studied as an enhancement (50 meters, 3σ).

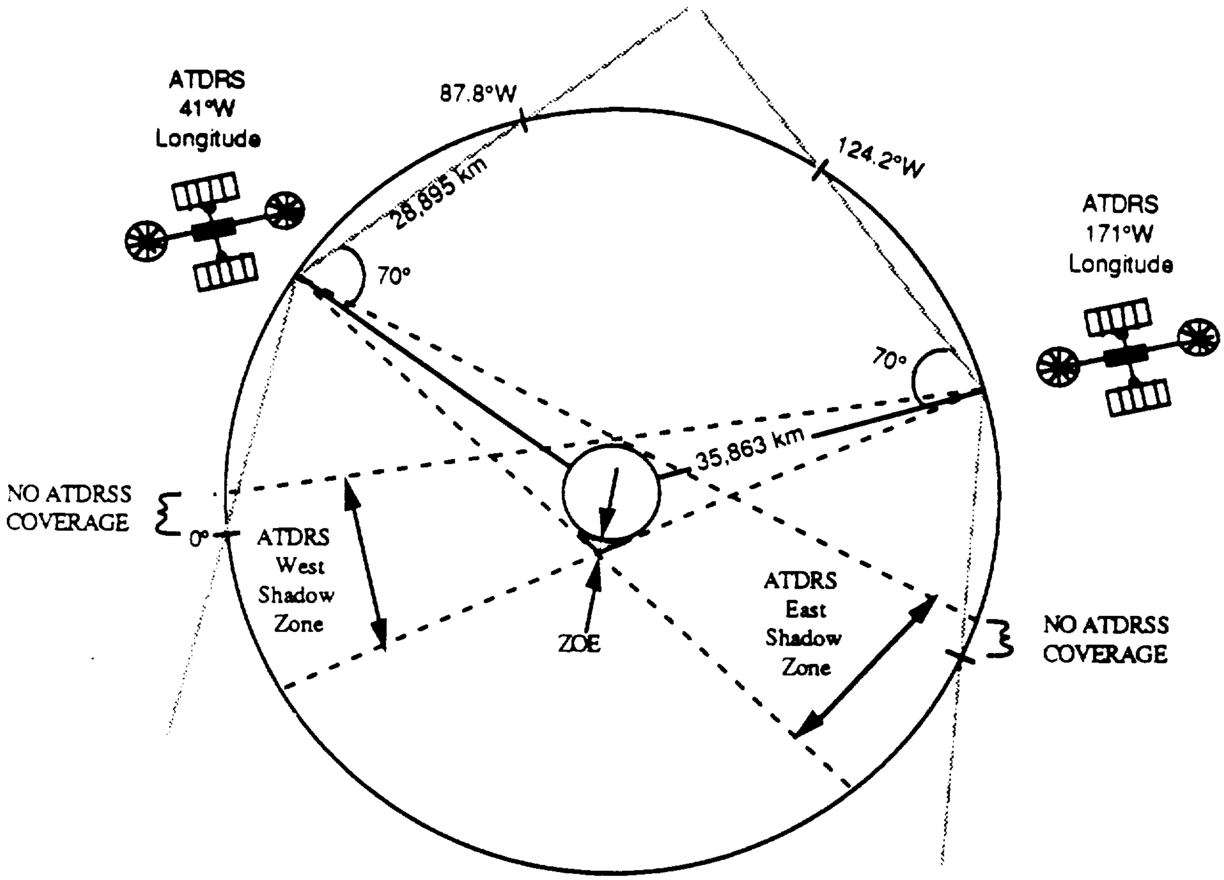

Figure 2.1-3. ATDRS Field of View (SSA)

2.2 NASA GROUND STATION CAPABILITIES

Table 2.2-1 identifies NASA and National Oceanic and Atmospheric Administration (NOAA) ground stations that may be available in the EES series time frame. The location of these stations are mapped in Figure 2.2-1.

Table 2.2-1. Locations of Available NASA Ground Stations

Station	Location	Functions
Bermuda, UK	65° W, 32° N	tracking,KSC launch
Canberra, Australia	149° E, 36° S	DSN
Fairbanks, Alaska	212°E,65°N	NOAA data reception
Goldstone, California	117° W, 35° N	DSN
Madrid, Spain	4° W, 40° N	DSN
Merritt Island, Florida	80° W, 28° N	tracking,KSC launch & landing
Wallops Island, Virginia	75° W, 38° N	tracking, launch

Note: DSN = Deep Space Network
KSC = Kennedy Space Center
NOAA = National Oceanic and Atmospheric Administration.

Communication between a ground station and a spacecraft in Earth orbit is only possible while the spacecraft is above the ground station horizon. Usable view periods range from approximately 5 minutes to 24 hours, depending on the spacecraft orbit.

When the baseband signal spectra are compatible, the uplink supports simultaneous command and ranging transmissions, and the downlink supports simultaneous telemetry and ranging reception. The available uplink and downlink frequency ranges are 2025 to 2120 MHz and 2200 to 2300 MHz, respectively.

NASA ground stations are equipped to modulate commands on a 16 kilohertz (kHz) subcarrier, thus limiting the command data rate to a maximum of approximately 8 kbps; 2 kbps is the norm. Downlink demodulation is supported to a maximum bandwidth of 10 MHz, corresponding to a maximum downlink bit rate of approximately 5 Mbps. Each ground station is capable of range and range rate measurements although current user transponders are not compatible with ground range and range rate signals. Orbit computation is performed in a central location at GSFC, with results fed back to the tracking stations to support continuing operations and to the science community to support data interpretation. If frequent tracking measurements are made, the position uncertainty of the computed orbit is typically less than 100 meters [Ref. 6].

The ground station interface with user spacecraft employs a continuous stream of serial data, while the ground station interface with NASA Data Capture Facilities uses a discontinuous stream of data blocks. Conversion and buffering for the latter interface are accomplished in data formatting equipment. The rate capability of this equipment potentially limits the rate of off-site data transmission. Whether this will be a problem for EES will depend on the required downlink data rate and whether there is a need to relay the data at full rate.

In general, each of the available NASA ground stations is capable of satisfying EES requirements as they are presently understood, providing that the EES communications system is designed and implemented to be compatible with NASA ground station interfaces. The NASA ground stations will be upgraded to be able to handle Consultative Committee for Space Data Systems (CCSDS) compatible EES communications, command and data processing.

2.2.1 Launch and Landing Ground Stations

NASA has tracking stations located at Merritt Island, Florida and Bermuda, United Kingdom. Each station uses a 9 meter antenna for S-Band support of launch and landing operations. These stations are also permitted to support orbiting spacecraft during spacecraft emergencies.

2.2.2 Wallops Island Orbital Tracking Station (WPS)

WPS has a charter to support Earth-orbiting spacecraft when TDRSS support is inappropriate. WPS currently supports the Interplanetary Monitoring Platform-8 (IMP-8), International Ultraviolet Explorer (IUE), Cosmic Background Explorer (COBE), and Nimbus-7. These spacecraft require a variety of communication alternatives: IMP-8 uses Very High Frequency (VHF) communication, IUE uses hybrid VHF/S-Band, and

Nimbus-7 uses S-Band. Except for COBE, these spacecraft were designed and built prior to the establishment of the SN.

The station presently operates around the clock, seven days per week. Adequate control room electronics and staffing are in place to support dual S-Band operations and one hybrid VHF/S-Band operation, i.e. the IUE. Solar cell and battery deterioration on IUE indicate it is unlikely to survive Earth shadow beyond 1994. The VHF support capability will probably be dropped with IUE. Therefore, Wallops post-IUE capabilities may be reduced to a single S-Band mission.

The Wallops Island 9-meter S-Band antenna would be the logical choice for EES operations since it has ample gain and can provide both uplink and downlink. Wallops Island uses additional S-Band antennas to support range operations. Under the terms of present agreements, these antennas cannot be committed support of Earth orbiting spacecraft, but can be used in contingency situations.

Wallops Island uses a unique data formatter which has been tested to 1 Mbps and which may be operable at somewhat higher rates. The analog tape recorder inventory includes four machines with a 2 MHz bandwidth, and one machine with a 4 MHz bandwidth. The data communications interface includes numerous terrestrial circuits, a Radio Corporation of America (RCA) satellite service, a 224 kbps Time Division multiplex Access (TDMA) interface, and a variable rate TDMA interface with a maximum capability of 1.544 Mbps.

Wallops Island is capable of supporting a single EES in non-equatorial orbit with minimal system enhancements and no staffing increase. However, both system enhancements and staffing increases may well be required if two or more EES required simultaneous support at Wallops Island.

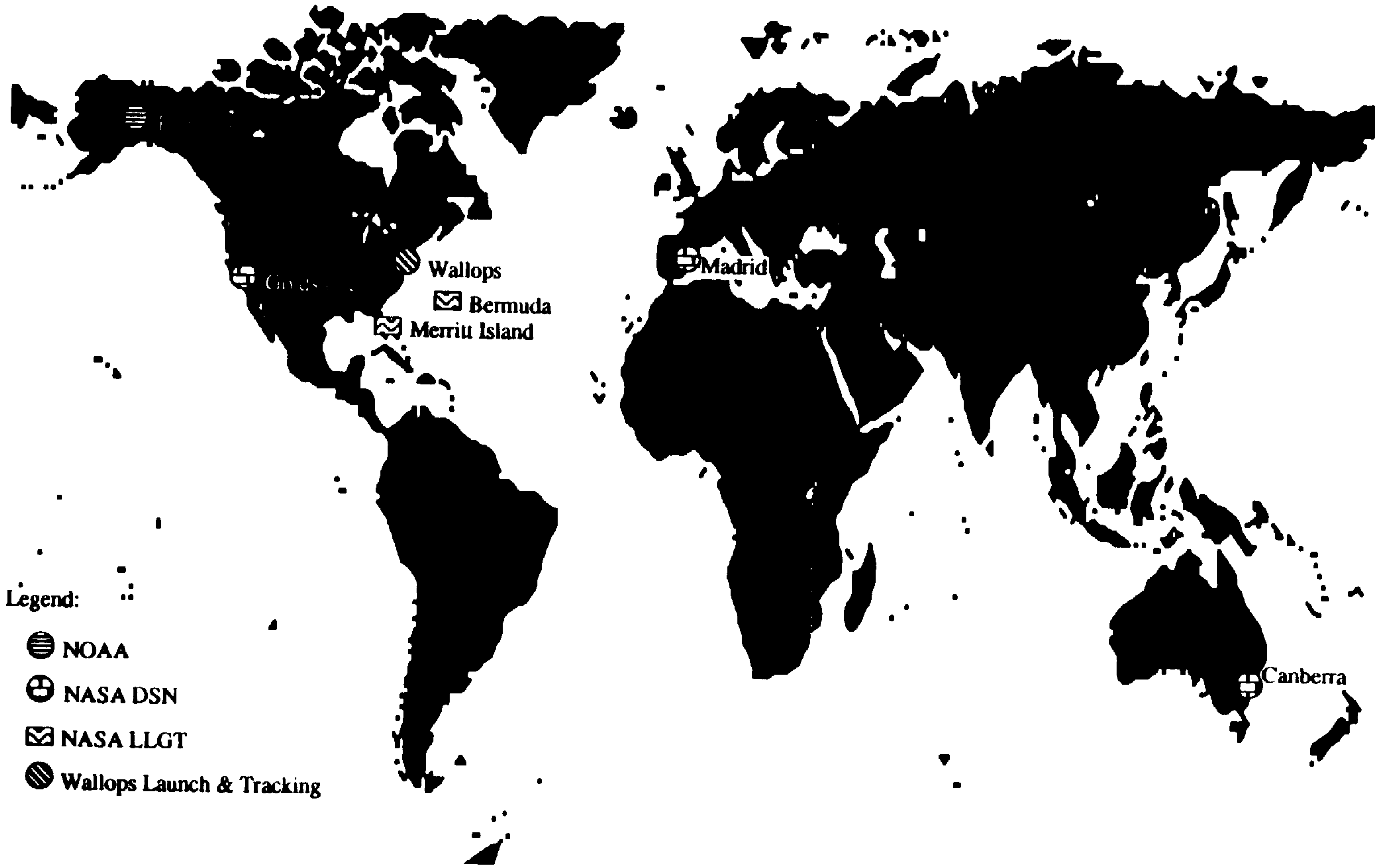

Figure 2.2-1. Locations of NASA and NOAA Ground Stations and Launch Sites.

2.2.3 Deep Space Network (DSN) 26-Meter Subnet

The DSN operates a subnet using 26-meter diameter antennas at three stations near Goldstone, California; Canberra, Australia; and Madrid, Spain. The Goldstone station also has a 9-meter antenna. This subnet is available to support Earth-orbiting spacecraft. The network operates around the clock supporting a set of ground-compatible spacecraft that includes Landsat, Nimbus, and Dynamics Explorer. The stations are located in mid latitudes and are capable of providing support for spacecraft launched from Merritt Island, Wallops Island, and Vandenburg Air Force Base, but not from San Marco. These locations are depicted in Figure 2.2-1.

The size and sophistication of the DSN antennas provide ample link margins for EES support. Data formatters currently in use are proven at 224 kbps and may be capable of higher rates with suitable programming. Data communication lines are limited to 224 kbps at Goldstone and 56 kbps at Canberra and Madrid. These stations are dedicated to the support of deep space missions. Currently, Galileo and Magellan are the deep space missions being supported by the DSN. An EES mission would have to be coordinated with any deep space missions of a specific time frame to get DSN support.

In addition to specific capabilities for supporting deep space probes, each DSN station is equipped with Launch and Landing Ground Station-unique hardware. The 26-meter subnet is capable of supporting EES in non-equatorial orbits with minor limitations. Science data downlink may have to be recorded at the station and played back later at reduced rates consistent with the available communication line bandwidth.

3.0 DRIVERS AND REQUIREMENTS

Section 3 briefly discusses Delta launcher performance in section 3.1, the requirements of the strawman instrument payloads in section 3.2, and orbit driven contact time constraints in section 3.3. These requirements are then used as the basis for analysis of design tradeoffs ("considerations") for the communications subsystem, data handling subsystem, and spacecraft operations discussed in Sections 4 and 5.

3.1 LAUNCH VEHICLE PERFORMANCE

The EES will be launched on a Delta 7920 or 7925 rocket. Figure 3.1-1 and Figure 3.1-2 are taken from the Delta users manual [Ref. 7] and show the apogees that various payload weights can be lifted to using a two stage or three stage Delta, respectively.

The Delta is capable of inserting payloads into low Earth, sun synchronous, high eccentricity, and geosynchronous orbits. The lift capabilities of the Delta and the subsequent constraints put on the payload weight and volume are discussed in an independent study performed by the EES Study Team. The drivers for this study on communications analysis are slant ranges generated by the range of possible orbits that can be achieved, and contact times that are observed for each orbit. From these the transmitter and antenna requirements are derived.

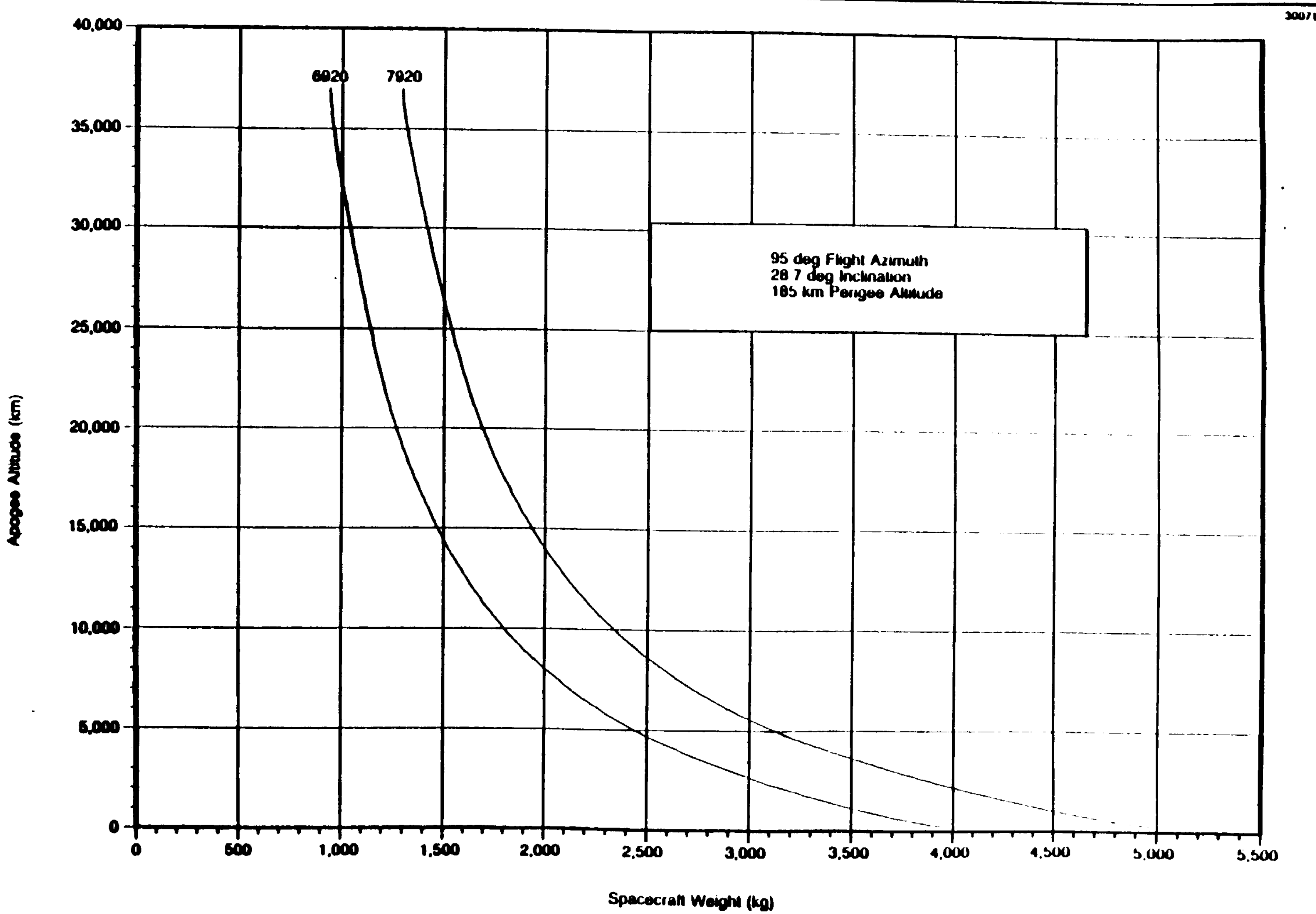

Figure 3.1-1 Two-Stage Apogee Altitude Capability (Metric Units) - East Coast Launch.

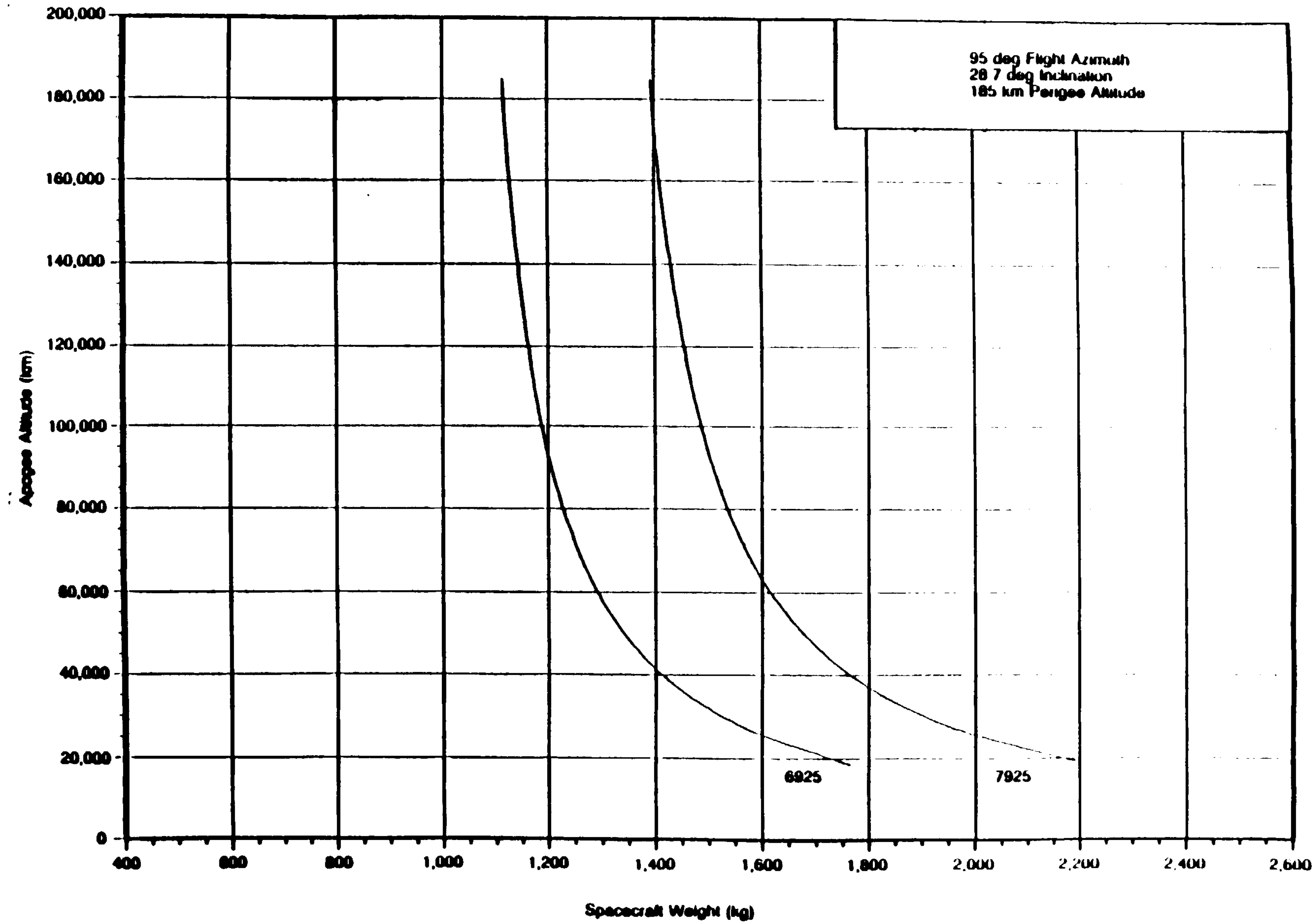

Figure 3.1-2 Three-Stage Apogee Altitude Capability (Metric Units) - East Coast Launch.

3.2 STRAWMAN INSTRUMENT CONSIDERATIONS

A list of strawman instruments was developed by reviewing responses to a "Dear Colleague" letter issued by NASA Headquarters. Responses came in the form of forty-five Explorer mission proposals [Ref. 1] which were sorted into six disciplines. The discipline groups are: Upper Atmosphere & Ionosphere (AERO); Ultra-Violet and Visible Astronomy and Relativity (EUVU); High Energy Astrophysics (Hi-E); Infra-Red and Radio Astronomy (IRSU); Magnetospheric Physics (MAGN); and Solar Physics (SOLR). Twenty-five proposals were picked as a test group for this study. The proposals used represent each discipline and include a wide range of parameters for power usage, orbit, data rate, dimensions, mass, pointing accuracy required, and mission length. Although these twenty-five experiments are a preliminary selection, they may be assumed typical of their fields of study, and were used to develop the EES mission model for the communication study. These strawman experiments were selected for this study strictly for the purpose of sizing data communications and processing requirements. Table 3.2-1 shows how many proposals were picked from each discipline and how many times each discipline is represented.

Table 3.2-1.Science Disciplines Represented by the Strawman

DISCIPLINE	NO. PROPOSALS EACH DISCIPLINE	NUMBER USED FOR TEST	NO. DISCIPLINES REPRESENTED
AERO	11	6	8
EUVU	13	5	5
Hi-E	12	6	7
IRSU	6	3	3
MAGN	8	2	5
SOLR	6	3	4
TOTAL	56	25	32

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Table 3.2-2. Strawman Experiments for Expendable Explorer Spacecraft

EXPERIMENT	MASS (kg)	POWER (Watts)		ORBIT			DATA RATE (kbps)			STABILIZATION	POINTING ACCURACY (Arcsec)		MISN LNTH
		PEAK	AVG	PERIG (km)	APOG (km)	INCL (deg.)	PEAK	AVG	DUTY CYC % ON		CTRL	KNLG	MO.
AEROS	425	100	50	600	2000	90	131	16	12	3 axis	3600	360	24
AIM	120		200	300	12000	90		14	100	Spin	3600	360	24
ARTBE	800		200	1000	13000	90	800	20		Spin	700	1080	24
Asteroseismology Explorer	700		200	500	500	57		36	100*	3-axis	350		12
Astro/Atmos Spect. Expl.	3100		600	500	500	97.5	300	300	100	3 axis	3		12
EMAO	1000	400	300	150	4000	90	200	20	25		600	600	24
EXCAM	850	110	110	500	500	28	500	30		3-axis	600		24
HEASI	2400		1500	600	600	28	1000	150	15	3 axis	32	2	36
HECRE	2500	375	375	500	500	28	102	100	10	Not Specified	10800		12
HXRE	450	75	75	600	600	28	20	20	100	3-axis	7200	348	36
HXSIE	3266	416	416	700	700	28	48	48		3 axis	300	10	36
IMAGE	200		210	19200	64000	90	90	11	100	Spin	1800	360	12
LUX	2000		500	500	500	28.5		120	100*	3 axis	1		36
LYMAN	1030		250	500	500	28.5	48000	24	100*	3 axis	0.10		36
MELTER	115		320	660	660	98		12	60	3-axis	80	70	24
Microphysics Explorer	400	200	100	350	1500	57		800	10	Not Specified	360	360	24
Multiprobe Expl. Misn.	300		100	500	15000	90		50		Spin	1800	360	12
NAE	1200	500	500	450	450	28	15	15	50	3-axis	60	60	24
NIREX	1200		50	700	700	28.5	4	4	100	3-axis	600		24
QUASAT	1000		1000	18900	33172	63	128000	128000	100	3 axis	60		24
SAMEX	400	95	95	2150	2150	106	53	53	100	3 axis	5	1	36
SHAPE	1565	500	500	500	500	28.5	2300	80	15	3 axis	120	0.20	36
SOFE	300	150	150	500	500	28.5		25	60	Not specified	10	5	12
SpEx	2000	800	80.	500	500	28.5	64	64	100*	3 axis	3	3	12
SYNOP	1050		225	36000	36000	0		0.04	100*	3 axis	3600		60

* 100% duty cycle assumed

APOG = Apogee
AVG = Average
CTRL = Control
CYC = Cycle
INCL = Inclination
KNLG = Knowledge
LNTH = Length
MISN = Mission
PERIG = Perigee

Nine of the proposals contained multidiscipline experiments, this is the reason the total number of proposals in each discipline is greater than the actual number of proposals. Seven of the multidiscipline experiments were used for this study. Table 3.2-2 lists the experiments and shows their proposed instruments masses, power requirements, orbit parameters, data rates, stabilization required, and pointing accuracy requirements.

Stabilization was included because antenna requirements for a spin stabilized spacecraft are different than for a three axis gyro stabilized spacecraft. Power and mass considerations are being addressed in another study but were included in Table 3.2-2 for information.

The data rate and duty cycle are used to indicate what the transmission rate will be during contact time. The orbit parameters are used for calculating contact times and maximum slant range, Not all the orbits fit into a specific orbit class but for the study purpose they were put in a class as shown in Table 3.2-3. These orbit classes will be discussed in section 3.3.

Since most of these instruments prescribe orbits which are very different from the five classes of orbits to be discussed (but still within capabilities of the Delta launch vehicle), they were analyzed separately from the five classes of orbits.

The EES Study Team expressed preference for supporting these instruments entirely from one or more ground stations, fearing that use of the TDRSS would impose complex and costly requirements for high power transmitters and steerable spacecraft antennas. The RF propagation path to a ground station is much shorter than the path to a TDRS. The obvious conclusion is that a less costly RF system, including a lower gain spacecraft antenna, would be required for transmission directly to ground, avoiding the long path to TDRS. Notwithstanding this, support via TDRSS is considered as part of this analysis and compared with support of the same spacecraft via one or more ground stations.

As an aid in this analysis, the strawman instruments have been grouped according to the criterion of whether the instrument orbit exceeded the allowable TDRS viewing angle. This grouping is shown in Table 3.2-4. The allowable TDRS viewing angle is explained in Section 2.1 and Section 2.1.3 for ATDRSS.

Table 3.2-3. Orbit Class Assigned

ORBIT CLASS	EXPERIMENT
1 Geosynchronous	SYNOP
2 Low Earth Orbit, 28 degree inclination	EXCAM HEASI HECRE HXRE HXSIE LUX Lyman NAE NIREX SHAPE SOFE SpEx
3 Polar Orbit	AEROS AIM ARTBE Asteroseismology Explorer* EMAO Microphysics Explorer* Multiprobe Explorer Mission
4 Sun-Synchronous Orbit	Astro./Atmos. Spect. Expl. MELTER SAMEX
5 Molniya	IMAGE QUASAT

* Actual inclination is 57 degrees.

Table 3.2-4. Strawman Instruments for EES That Can Be Supported By TDRSS

Instrument	Mass (kg)	Perigee (km)	Apogee (km)	Incl(°)	Data Rate (kbps)	
					Max	Avg
Instruments with limited TDRSS coverage						
IMAGE	200	19,200	64,000	90	90	11
QUASAT	1,000	18,900	29,560	63	128,000	128,000
SYNOP	1050	36,000	36,000	0	0.04	0.04
Instruments with near-continuous TDRSS coverage						
Astro/Atmos	3,100	500	500	97.5	300	300
AEROS	425	600	2,000	90	131	15
AIM	120	300	12,000	90	14	14
ARTBE	800	1,000	13,000	90	800	20
Asteroseismo	700	500	500	57	36	36
EMAO	1,000	150	4,000	90	200	20
EXCAM	850	500	500	28	500	30
HEASI	2,400	600	600	28.5	1,000	150
HECRE	2,500	500	500	28.5	102	100
HXRE	450	600	600	28	20	20
HXSIE	3,266	700	700	28	48	48
LUX	2,000	500	500	28.5	120	120
Lyman	1,030	500	500	28.5	48,000	24
MELTER	115	660	660	98	12	12
Microphysics	400	350	1,500	57	800	800
Multiprobe	300	500	15,000	90	50	50
NAE	1,200	450	450	28	15	15
NIREX	1,200	700	700	28.5	4	4
SAMEX	400	2,150	2,150	106	53	53
SHAPE	1565	500	500	28.5	2,300	80
SOFE	300	500	500	28.5	25	25
SpEx	2,000	500	500	28.5	64	64

In theory, a spacecraft in a highly elliptical orbit could be supported by TDRSS during those times when it was within the allowable viewing angle. Contact times for six of the orbits (AEROS, AIM, ARTBE, EMAO, Microphysics Explorer, and Multiprobe Explorer Mission) that fell within TDRSS coverage zone were analyzed over a two day period. It was found that orbits that went outside the TDRSS coverage zone by only a few thousand kilometers could be handled by TDRSS. Tables 3.2-5 and 3.2-6 show the times during which the Multiprobe Explorer Mission would be visible to one of the TDRS or to a ground station [Ref. 8]. Apogee occurs over the Indian ocean in one table and perigee occurs over the Indian ocean in the other table. These configurations were chosen since they would produce the longest periods of non-contact with a TDRS. The longest period of loss of sight by both TDRS was 20 minutes and occurred twice in two days. It appears the TDRSS can be used for highly elliptical orbits that extend as far as 3000 km beyond the 12000 km outer limit. Note that when ATDRSS is in full operation all orbits of the strawman instruments could be supported, in theory, as is explained in Section 2.1.3 and shown in Figure 2.1-3.

Table 3.2-5. Contact Times for Multiprobe (Apogee over Indian Ocean)

Multiprobe

Apogee over the Indian Ocean

Event #	Satellite view time (in minutes) at the given stations.						
	TDRS1	TDRS2	Wallops WPSA	Goldstone DS 16	Alaska ULAE	Canberra DS 46	Madrid DS 66
1	630.00	265.50	155.10	167.56	99.49	19.42	28.96
2	388.00	252.00	50.63	126.02	103.00	134.27	7.41
3	254.00	646.00	15.57	15.89	76.65	168.57	98.72
4	629.00	423.00	136.43	165.63	39.25	15.16	152.37
5	371.00	252.00	161.90	139.98	34.96	118.56	53.59
6	257.00	629.00	18.08	6.57	92.02	170.11	14.49
7			59.47		98.41	18.23	155.37
8					84.25		63.29
9					46.51		
10					30.29		
11					80.06		
Mean	421.50	411.25	85.31	103.61	71.35	92.05	71.78
Median	379.50	344.25	59.47	133.00	80.06	118.56	58.44

Period = 4.64 hours Inclination = 90 degrees

Table represents events during a 2 day period.

Table 3.2-6. Contact Times for Multiprobe (Perigee over Indian Ocean)

Multiprobe

Perigee over the Indian Ocean

Event #	Satellite view time (in minutes) at the given stations.						
	TDRS1	TDRS2	Wallops WPSA	Goldstone DS 16	Alaska ULAE	Canberra DS 46	Madrid DS 66
1	543.50	367.00	69.63	16.81	32.36	77.72	56.71
2	253.00	367.00	160.79	119.49	40.07	18.96	152.05
3	391.00	261.00	121.01	167.68	80.80	170.53	61.82
4	631.00	256.00	15.91	17.91	100.36	118.15	13.20
5	252.00	374.00	60.36	85.72	101.75	17.54	44.83
6	645.50	628.00	153.38		37.55	168.49	146.50
7		253.00	156.32		36.80	66.46	131.36
8					73.85		166.81
9					105.42		
10					108.96		
Mean	452.67	358.00	105.34	81.52	71.79	91.12	96.66
Median	467.25	367.00	121.01	85.72	77.33	77.72	96.59

Period = 4.64 hours Inclination = 90 degrees

Above table represents events during a 2 day period.

3.3 SPACECRAFT ORBIT CONSIDERATIONS

Each spacecraft in the EES series is planned to be placed into orbit using a Delta launch vehicle, with the choice of orbit parameters depending on the instrument(s) carried on that particular spacecraft. The Delta launch vehicle can launch into a significant range of possible orbits, of which five were chosen for emphasis in this study.

3.3.1 Types of Orbits to be Supported

The following five typical orbits have been chosen by the EES Study Manager for emphasis.

a. Geosynchronous orbit: 0° Inclination, 36,000 km Altitude

b. Circular orbit: 28° Inclination, >500 km Altitude

c. Polar Orbit: 90° Inclination, >500 km Altitude

d. Sun-synchronous orbit: 97° Inclination, >700 km Altitude

e. Molniya: 63.4° Inclination, 370 - 40,000 km Altitude

All orbits except the geosynchronous and Molniya orbits are capable of being supported by current TDRSS capabilities, although ATDRSS may be able to handle these orbits too. In addition, all these orbits are capable of being supported by one or more ground stations, but the percentage of time the EES could be in contact with the ground station(s) would be much less than for TDRSS.

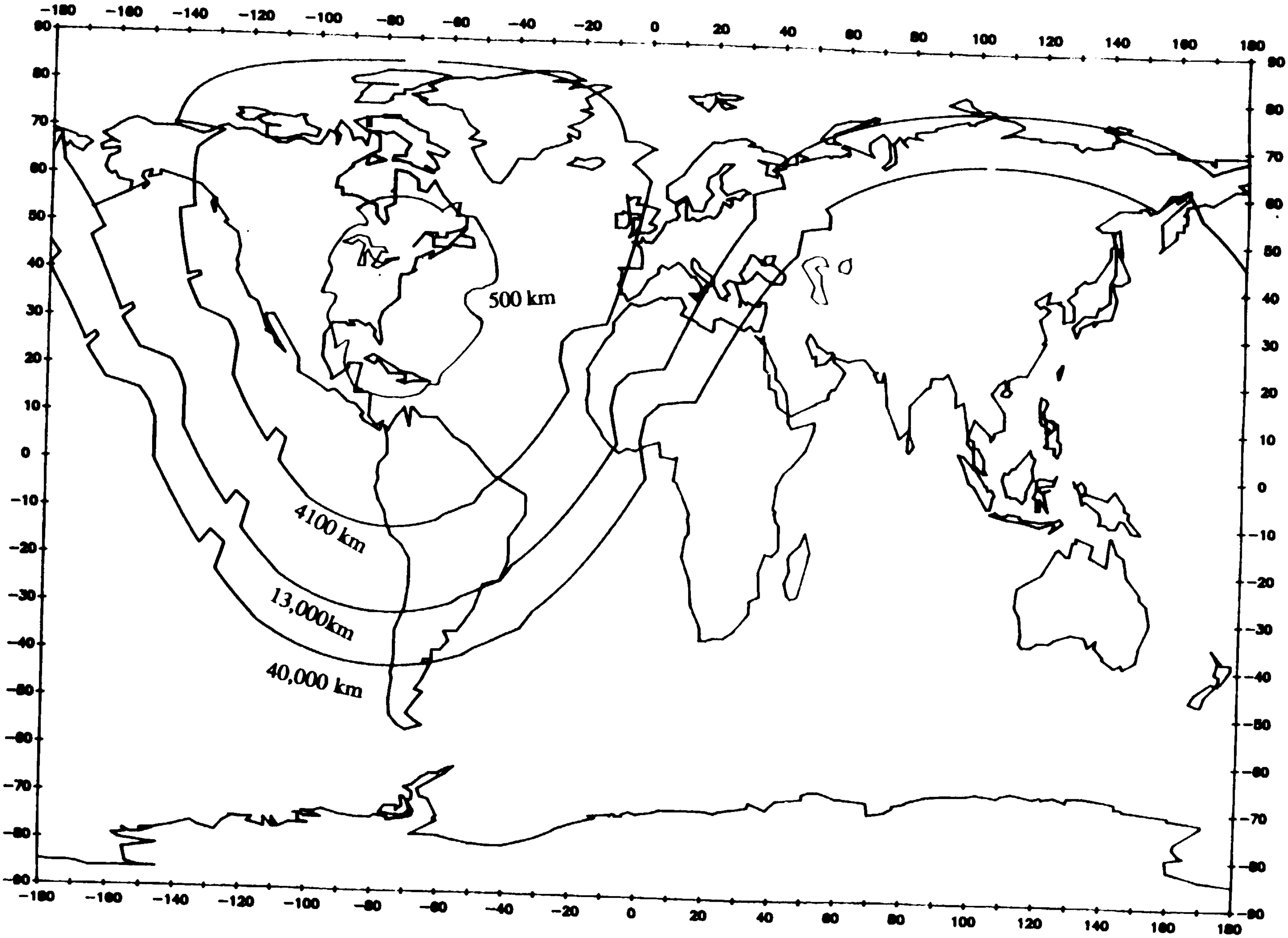
The Molniya orbits would require a direct downlink to one or more ground stations exclusively, as current TDRSS support is limited to spacecraft which have altitudes of less than 12,000 km. However, ATDRS could handle a significant portion of a 12-hour Molniya orbit.

3.3.2 Coverage Using Ground Stations

NOTE: The coverage diagrams shown in this section have been reproduced from, or adapted from coverage diagrams produced by GSFC Code 531.1 in support of this study.

A ground station of the surface of the earth can observe a portion of the sky which is defined by a conical shape having the apex at the site of the station, the major axis of the cone perpendicular to the surface of the earth and the size of the apex angle of the cone defined by the angle from local zenith over which the ground station antenna can be pointed. When a satellite orbit intersects this cone, the ground station can contact the spacecraft. The area of the sky over which contact with a spacecraft can be made depends on the angles over which the ground station antenna can be pointed and the height of the spacecraft above the station. In practice, a ground station antenna can "see" nearly 85° each side of local vertical, with some portions limited by local terrain. From this information, it is possible to sketch the coverage of a ground station for different satellite altitudes. Figure 3.3-1 shows the coverage of the Wallops ground station for different satellite altitudes. The shape of the coverage circle for the 500 km altitude is distorted from a circle by local terrain, and this distortion also applies to viewing at higher altitudes. The plot of Figure 3.3-1 for the higher altitudes is distorted because the map projection represents the spherical earth on a flat sheet of paper; coverage circles which include the north pole appear as strange open shapes covering the northern regions of the map.

Figure 3.3-1 Coverage by Wallops at Various Orbital Altitudes



The geometry of a contact between a spacecraft and a supporting ground station is complicated by the following factors:

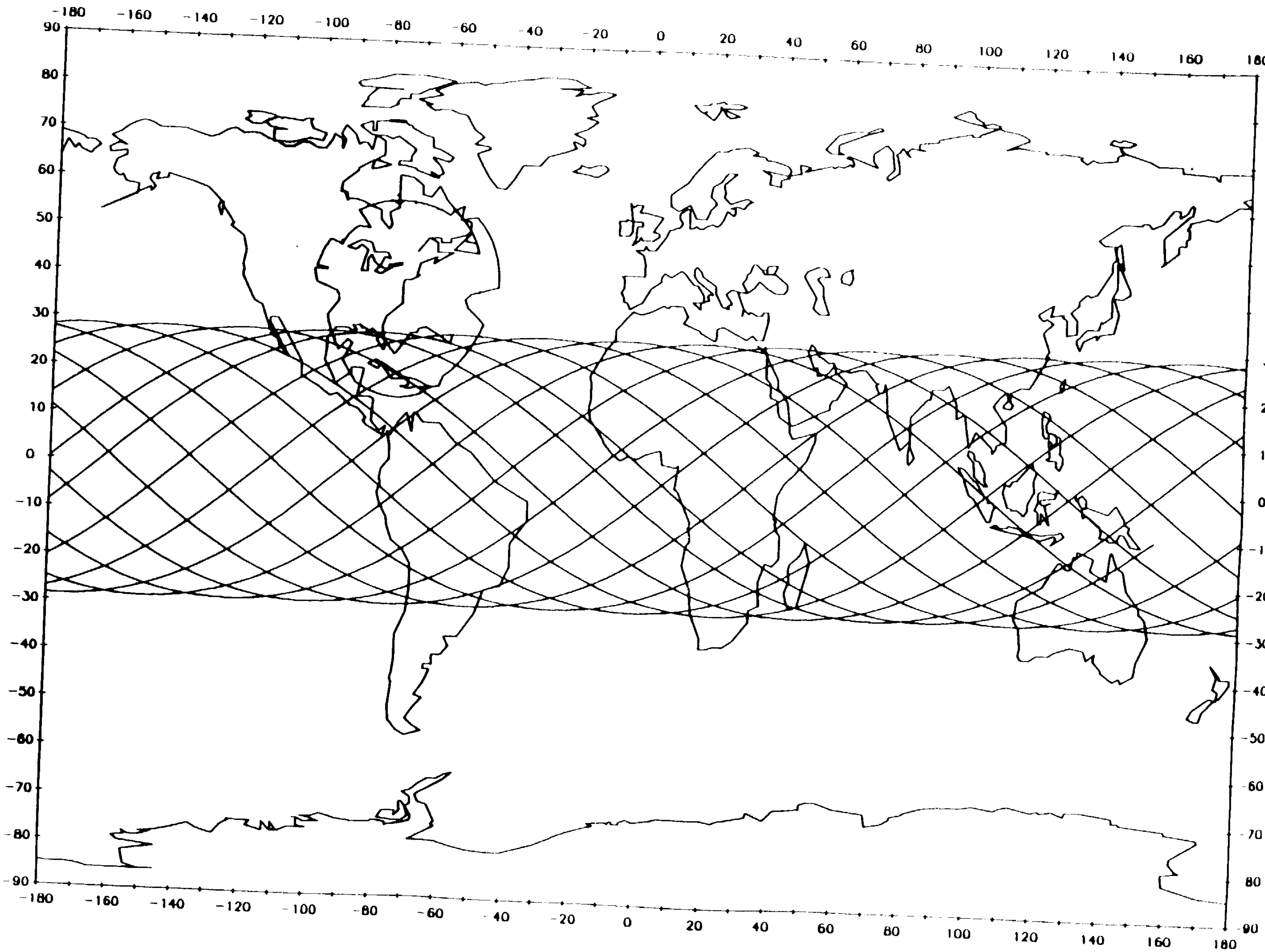
- The earth rotates a nominal 360° in 24 hours, which causes a point on the surface to move from west to east at a rate which is an inverse function of the ground latitude. A point on the equator moves at about 1,700 km/hour. A point very near the pole would move hardly at all in the same time.

- The spacecraft moves in its orbit, with a velocity which depends on the altitude of the spacecraft above the earth. Spacecraft in low altitude circular orbits move more quickly than those in higher orbits; spacecraft in elliptical orbits move with varying velocity depending on the instantaneous spacecraft altitude. The amount of time required to complete one orbit of the spacecraft is not necessarily a multiple of 24 hours, so a spacecraft in a stationary orbit which passed directly overhead at a specific time on a specific day probably would be far from overhead exactly 24 hours later.

- The plane of the satellite orbit can rotate slowly (precess) around the earth at a speed which is a function of the spacecraft orbital elements, but often amounts to 6.5° per day. Thus, a point on the earth passing through the plane of a spacecraft orbit at a specific time on a specific day would probably be significantly displaced from the orbit plane exactly 24 hours later. Calculating link margins for elliptical LEOs is made difficult by this point since precession of perigee makes contact times and slant ranges variable at a specific ground station.

If one were to plot the line directly beneath a spacecraft (locus of spacecraft nadir points) on the surface of the earth for a spacecraft in a circular orbit, it would resemble a sine wave having an amplitude equal to the orbit inclination and a period related to the inverse of the orbit altitude. This is shown in Figure 3.3-2, showing 24 hours of the subsatellite plot for a spacecraft in a 500 km circular orbit of 28.5° inclination. If this plot were continued for a very large number of days, every point on the earth between 28.5° north and south latitude

Figure 3.3-2 Suborbital Plot for 28.5 Degree Inclination 500 km Circular Orbit



would be covered. A special case of the circular orbit is the geosynchronous orbit, having an orbital period of 24 hours. The subsatellite plot for that orbit would be a single point on the equator for a spacecraft having an inclination of 0°, or a vertical line extending to the north and south orbit inclination. (These generalizations ignore slight variations caused by the imperfect spherical shape of the earth or slight deviations from perfectly circular spacecraft orbits.)

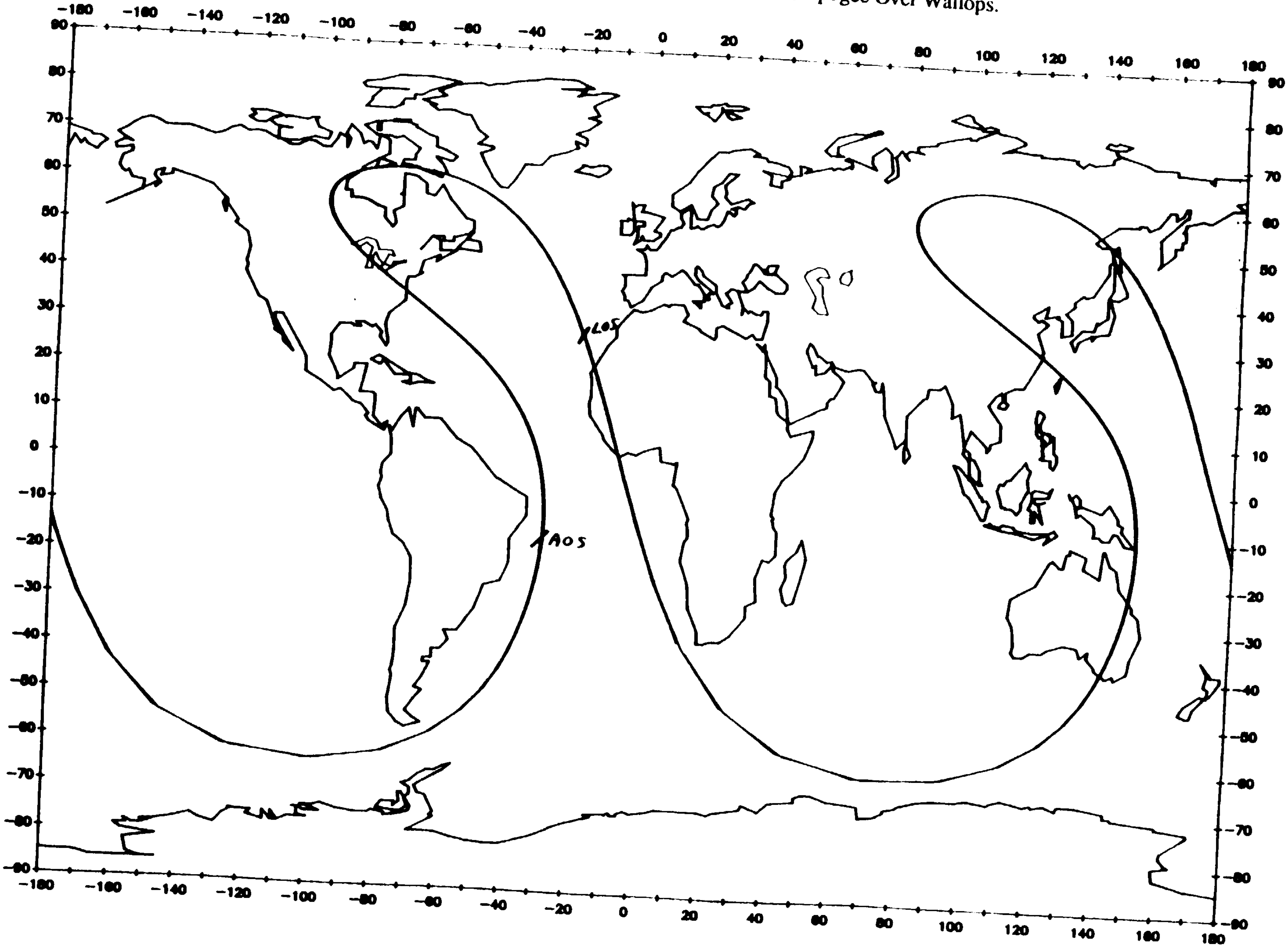
Figure 3.3-3 shows the subsatellite plot for the special case of an elliptical orbit called a Molniya orbit. This case plotted is an orbit having a period of 12 hours, with perigee of 370 km and apogee of 40,000 km. The orbit has a 63° inclination which causes the spacecraft to pass over exactly the same point of the earth every day. In this case, the spacecraft appears to move from west to east at low altitudes and then reverses direction at high altitudes. The shape of this plot is further distorted by the fact that the map on which it is plotted has significant distortion beyond 45° north and south latitude.

Subsatellite points for other elliptical orbits were not plotted due to the complicated nature of the orbit. For example, if perigee of a polar elliptical orbit is near the South Pole it will precess northward to the North Pole in 15 to 30 days, depending on the orbit parameters, and then precess back south again. Fifteen to thirty plots would be needed to follow perigee from south to north. It follows that the spacecraft communications would have to be engineered to handle two constraints in order for one ground station to support it. The first is the minimum contact time when perigee occurs directly over the ground station. The second is when apogee occurs at the station horizon producing the maximum slant range. Since every strawman experiment with a 90 degree inclination has an elliptical orbit the above discussion becomes a serious consideration for the EES communications design. To avoid designing the spacecraft out of budget to meet the minimum contact time constraint two other options can be considered. First, all of the strawman experiments listed as polar orbits in Table 3.2-3 can be supported by TDRSS. Second, depending on the orbit parameters, the minimum contact time constraint will last only five to ten days during a 30 to 60 day period respectively. If two ground stations lie on the opposite side of the world from each other than when one has short contact times with a spacecraft in and elliptical orbit the other will have long contact times. If appropriate arrangements are made, a ground station in the southern hemisphere (e.g. Canberra Australia) could support the spacecraft during the periods when contact time with a northern hemisphere ground station (e.g. Wallops Island) is to short to complete a downlink of the data.

Returning to Figure 3.3-2, the amount of sky which can be viewed from the Wallops station is plotted as an irregular, nearly circular shape centered at 38° north and 77° west. As mentioned earlier, the irregularities are due to terrain masking. The figure demonstrates that the station would be capable of making contact with the spacecraft on several successive orbits, but then could not see the spacecraft until the next day. Figure 3.3-4 shows an enlarged section of Figure 3.3-2, emphasizing the area near the Wallops station. From that figure, contact with the spacecraft can be made on 5 successive orbits, with no additional contacts until a day later. Some days there may be only 4 contacts, depending on the relative position of the ground tracks and the station. Note that, of the five passes, the first in each day move in a northerly direction while the last passes move south. This is typical of ground station contact with a spacecraft where the ground station is located farther north or south than the orbit inclination.

Figure 3.3-5 is an enlarged section of the subsatellite plot for Wallops support of a spacecraft in a near-polar orbit of 830 km altitude. In this case, the orbit inclination is significantly larger than the latitude of the supporting ground station. This figure also shows 5 contacts in one day, but timing of the contacts is different. The northbound group of passes is significantly separated in time from the southbound passes. What has happened here is that the ground station location has intersected the orbit plane for three northbound passes, the spacecraft has passed out of view of the station for several orbits, then the ground station location has intersected the orbit plane again on the same day, seeing the spacecraft on the "backside" of the orbit.

Figure 3.3-3 Suborbital Plot for the Molniya Orbit, Apogee Over Wallops.



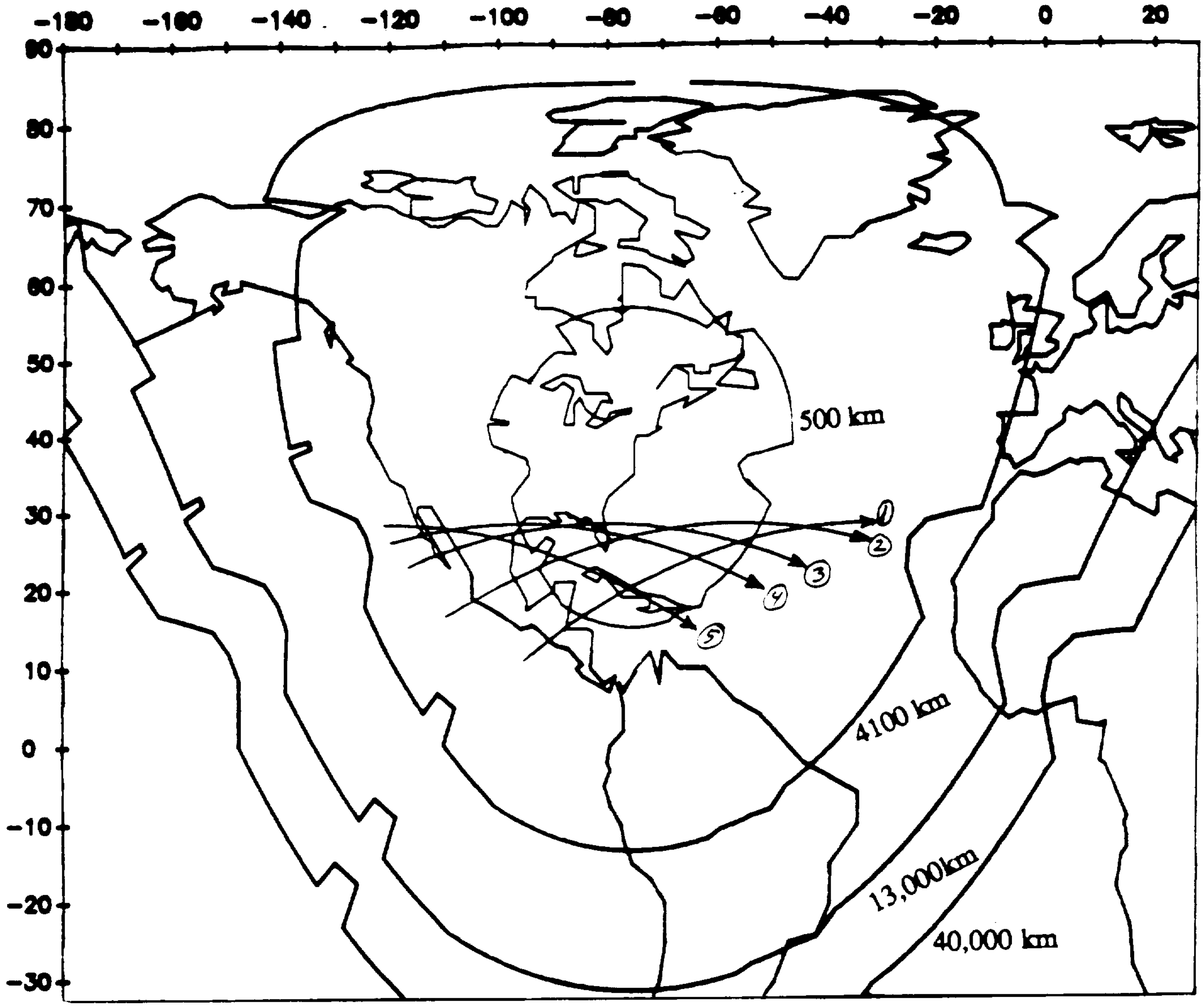
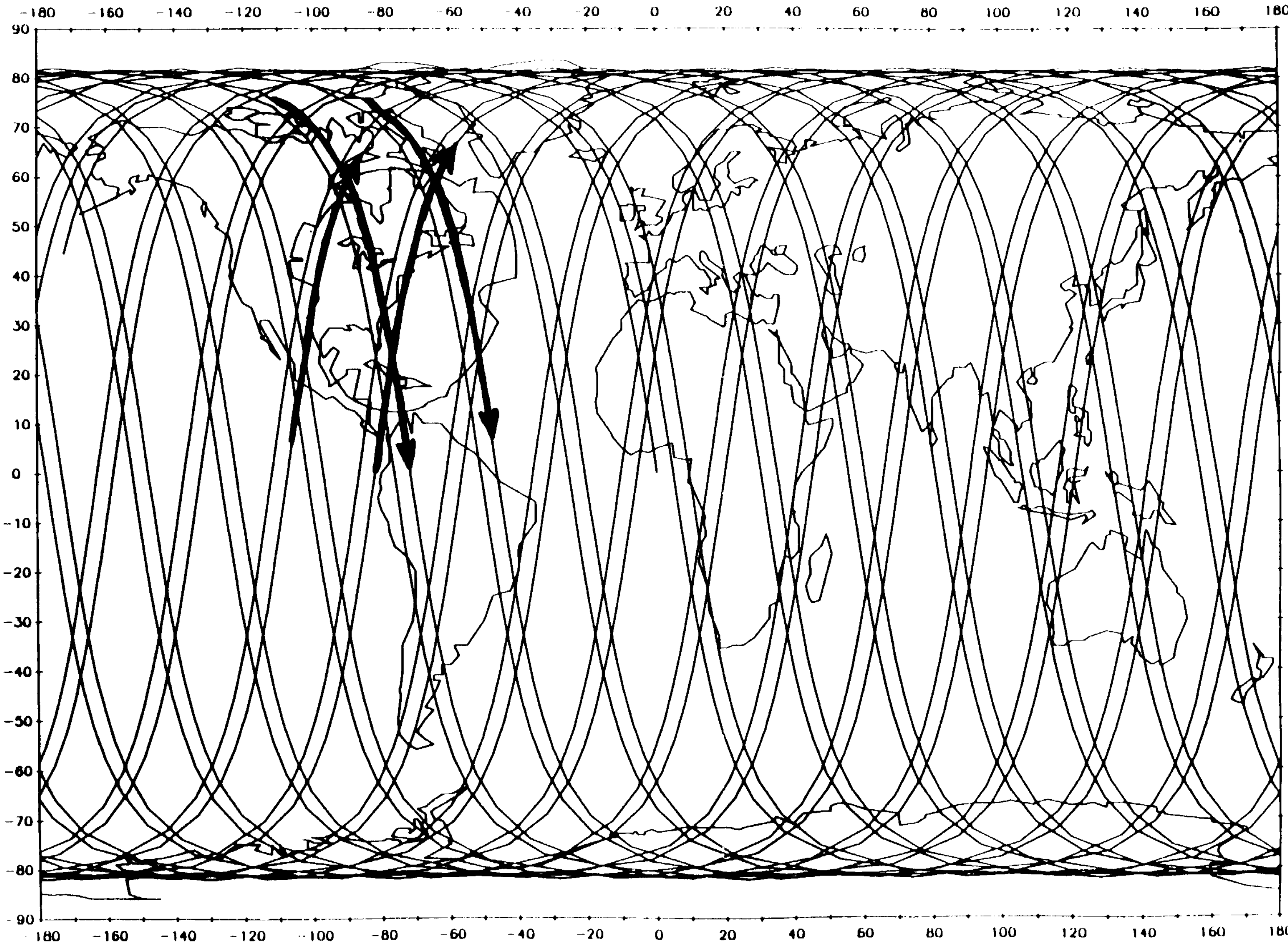


Figure 3.3-4 Typical 28 Degree LEO Sequence of Contacts with Wallops

Figure 3.3-5 Typical Sun-Synchronous LEO Sequence of Contacts with Wallops
833 km Circular Orbit, 89 Degree Inclination.



One of the strawman instruments specifies a 57 degree inclination circular orbit. This mid-range inclination orbit will produce passes over the ground station in an uneven interval. That is, the spacecraft will make a couple passes over the ground station and then will not be seen for about five hours, at which time it will make a couple more passes over the ground station. The spacecraft will then not be seen for about 12 to 14 hours, at which time it will make a couple more passes over the ground station and then repeat the pattern [Ref. 8]. For this orbit the 24 hours onboard storage of data is not needed as for the 28 degree LEO and 12 hours onboard storage of data may not be sufficient as it is for the truly polar orbits.

The specific number of minutes a day a ground station will contact a spacecraft depend on the station location and the orbit geometry, with contact ranging from about 30 minutes a day for Wallops support of a 500 km 28° LEO to several hours a day for a Molniya orbit with apogee placed over the supporting ground station. If a ground station were placed on or near the equator to support a spacecraft of 0° to 10° inclination, the station could contact the spacecraft on every orbit, with the contact time each orbit depending on the orbit altitude.

3.3.3 Contact Time Constraints

The contact time with a spacecraft cannot exceed the aggregate view period from all communications contact points used to support the spacecraft. Thus, a LEO spacecraft supported by TDRSS has a nearly full-time view period, being out of view only during passes through the ZOE. A low altitude spacecraft or an elliptical orbit spacecraft which is supported by ground stations will have a significantly shorter view period because of the limited portion of the orbit viewable from ground station locations. This limitation is exacerbated by the very small number of ground stations which will exist during the EES era. Not even during pre-Shuttle manned flight programs, using some two dozen ground stations, was nearly continuous coverage of a low altitude spacecraft achievable using ground stations.

In practice, the actual contact time will be less than the view period due to both technical and programmatic considerations. Typical technical considerations include the time required to transfer between TDRSs if only one mechanically steerable high gain antenna is used on the supported spacecraft, blockage of the view from the spacecraft to TDRS by the spacecraft body or appendages on the supported spacecraft, or look angle constraints on the line of sight from the spacecraft antenna to the TDRS for certain attitudes of the supported spacecraft. Typical programmatic considerations include agreements concerning the maximum volume of data or transmission time allowed a specific spacecraft, or requirements of higher priority spacecraft for use of the same data handling facilities at the same time.

Exact view periods for various strawman orbits with various ground stations and with TDRSS were calculated by Code 554.0 using a computer algorithm called ACQSCAN. Typical view periods for the strawman experiments where then produced by taking and average of the exact values. Individual contact times less than five minutes in duration are useful for commanding but are not useful for downloading the data so they where not figured into the average. The typical view periods derived from the Code 554.0 data appear in tables in Appendix A.

SECTION 4 - SPACE SEGMENT COMMUNICATIONS AND DATA HANDLING SUBSYSTEMS, DESIGN CONSIDERATIONS

This section discusses considerations which will affect design choices for the EES space segment communications and data handling subsystems. Pertinent aspects of the designs adopted by the EES Study Team for the communications and data handling subsystems are summarized in Section 4.1. Sections 4.2 through 4.6 discusses considerations which each of the selected orbits and candidate instruments for these orbits would impose on the EES design. These considerations are discussed in reference to the background, requirements and drivers already presented in Sections 2 and 3. No single solution represents an optimal choice for all orbits and candidate instruments covered in this study.

4.1 SPACECRAFT SUBSYSTEM DESIGN

The design approach for the space segment communications and data handling subsystems adopted by the EES Study Team employs a baseline system and enhanced versions [Ref. 2], all of which operate at S-Band. This report has studied the baseline and enhanced version as follows:

- The baseline design providing an average bit rate of 10 kbps, using a TDRSS-compatible transponder and omnidirectional antennas. Note that this design cannot be used to transmit greater than 4 kbps via TDRS [Ref. 2]; higher rates will be transmitted directly to a ground station.

- An enhanced design providing an average bit rate of 100 kbps, using a TDRSS-compatible transponder and a high gain antenna. Note that this design can be used to transmit any data rate the TDRSS SSA system can handle.

During the course of the study, there was a report of a low-cost TDRSS transponder being developed by GSFC Code 531. This transponder was investigated and found to be a low-cost transponder developed for a balloon test program; the transponder was low-cost because the program did not require use of space-qualified components. Such a transponder cannot be recommended for the EES application, and the cost of achieving space-qualification would be between 5 and 10 million dollars.

In principle, the SN with two operating TDRSs provides near-continuous coverage, allowing data to be transmitted in real time. The spacecraft geometry and mission pointing requirements for a specific spacecraft, however, may limit the time that the spacecraft can point its antenna(s) to a TDRS. In the case of COBE, this effect limited the coverage time to between 17% and 36%, depending on the season. Scheduling of communication, passage through the zone of exclusion, transfers between TDRSs, and maintenance periods will also reduce the coverage time available. Therefore, on-board data storage will be required even with SN communication. Dual recorders would be necessary for redundancy and uninterrupted data recording during playback periods.

4.1.1 Baseline Design

This design is conceived as being a spacecraft generating an average data rate of 10 kbps, including 1 kbps of engineering data, science data, overhead for CCSDS packetization, and any error correction coding desired in addition to the TDRSS convolutional encoding. The overhead for error correction will be reduced tremendously if the Reed Solomon encoding is used. This design is conceived as using a TDRSS-compatible transponder and an omnidirectional spacecraft antenna for tracking, receipt of commands, and return of real-time telemetry, with the restriction that the low power transmitted by the spacecraft will limit the data rate transmitted to TDRSS to less than 4 kbps. TDRSS contacts would be scheduled on about six-hour intervals for transmission of engineering real-time data, commands and tracking data; with each contact lasting a nominal 20 minutes.

In addition to data transmission via TDRSS, the spacecraft would transmit stored engineering and science data directly to a ground station when it is within view. Because the propagation distance from the spacecraft to a ground station would be significantly shorter than the transmission distance to a TDRS, the spacecraft Radio Frequency (RF) subsystem could support a much higher data rate when transmitting to a ground station than would be possible via TDRSS.

The baseline design would include on-board data storage of as much as 3 Gigabits (Gbits), which would be transmitted directly to a ground station as the Effective Isotropic Radiated Power (EIRP) generated by the baseline design could not accommodate high data rates transmitted via TDRSS.

4.1.2 Enhanced Design

This design is conceived as being a spacecraft generating an average data rate of 100 kbps from the spacecraft, including 1 kbps of engineering data, science data, overhead for CCSDS packetization, and any error correction coding desired in addition to the TDRSS convolutional encoding. This discussion assumes the enhanced system would use a TDRSS-compatible transponder and a high gain spacecraft antenna for tracking, receipt of commands, and return of either real-time or stored telemetry. TDRSS contacts would be scheduled on about six-hour intervals, with each contact lasting a nominal 20 minutes.

This design would also include on-board storage of 3 Gbits of data, which would be transmitted via TDRSS or directly to one or more ground stations, with the choice of transmission path depending on the orbit of the spacecraft.

4.2 SPECIAL CONSIDERATIONS FOR A GEOSYNCHRONOUS ORBIT

The geosynchronous orbit (GEO) can only be supported by TDRSS if it is placed correctly in orbit where a TDRS can view it. Until ATDRSS is in place, it is more likely that all communication to the GEO spacecraft would be via a ground station. Either Wallops or GSFC could be used as the location of the ground station for a GEO of 28° inclination, provided the subsatellite point were kept between 40° and 110° west longitude.

When using a spacecraft antenna of 19 dB gain, the communication subsystem will support transmission of 100 kbps. Thus, the baseline design case could be supported provided playback were kept to 100 kbps.

The candidate instrument for a GEO, SYNOP, is listed with a very low bit rate which should pose no design problem. However, we believe that the stated data rate is in error since the mission expects to be an IUE type. Therefore, a 20 to 40 kbps data rate is more reasonable and 40 kbps is the value used in this study. A final consideration is that a minimum of two ground antenna systems should be capable of supporting the spacecraft, providing redundancy should the primary ground communication system be temporarily disabled.

4.3 SPECIAL CONSIDERATIONS FOR A 28° INCLINATION LOW EARTH ORBIT

The baseline design, with a ground station at Wallops or GSFC, could support the 28° Low Earth Orbit case for either 10 kbps or 100 kbps average data rates, and could support dumps of stored data at rates of 3 Mbps. TDRSS could be utilized for tracking, commands and real-time data, provided the return data rate did not exceed 4 kbps.

The major restriction when supporting this orbit with a ground station at Wallops or GSFC is the amount of time the spacecraft would be out of view. The spacecraft could be viewed on four or five successive orbits, covering a span of 6 to 7.5 hours, with no further contact until the next day. At the 100 kbps average rate, dump of the day's stored data might require two contact periods. As long as there is a redundant storage device on-board, this could be accomplished at the price of a more complex data management scenario than would be required if all data could be dumped during a single contact period.

Of the instruments listed in Table 3.2-3 which would require a 28° LEO, any of the 12 could be supported with the following exceptions:

- HEASI and LUX are listed with an average bit rates of 150 kbps and 120 kbps respectively, which should pose no problem since the system would be capable of supporting data rates much higher than that.

- Lyman is listed with a peak data rate of 48 Mbps, which cannot be supported with an S-Band transponder. An X-Band or K-Band system would be required, which is beyond the capability planned to EES.

4.4 SPECIAL CONSIDERATIONS FOR A 90° INCLINATION LOW EARTH ORBIT

In most respects, the communications and data storage subsystem considerations for this case are the same as those for the 28° LEO. The most significant difference is that the 90° orbit inclination would result in a total of 4 or 5 passes a day being visible from Wallops or GSFC, with these passes being spread across two groups of view periods separated by 12 hours. For planning purposes, one could count on 2 passes of 12 minutes separated by 95 minutes, followed by 2 more passes 12 hours later.

Of the instruments listed in Table 3.2-2, seven of them are candidates for a 90° LEO, but none of them could be satisfied by the baseline design because the average bit rate would exceed 10 kbps. However, the needs of AEROS and AIM, with average bit rates of 16 kbps and 14 kbps respectively, could be satisfied with adjustment of the instrument requirements and careful optimization of the baseline design. Still, it might be necessary to increase the baseline capability of the baseline design. Six of the instruments could be easily supported by the enhanced design.

Of them, ARTBE and Multiprobe Explorer Mission are listed with orbital which only slightly exceed the 12,000 km limit for full-time TDRSS coverage. ARTBE and Multiprobe Explorer Mission have data rate requirements which could be satisfied by the EES enhanced design.

The other instrument, Microphysics Explorer, is listed with an average bit rate of 800 kbps, which cannot be satisfied by either of the proposed EES designs. This instrument would generate 7×10^{10} bits every 24 hours, requiring very large on-board storage if it were supported by a ground station. If it were supported by TDRSS, it would require K-Band communications because a reasonable data storage and dump scenario would exceed the 3 Mbps rate supportable at S-Band, but K-Band has been excluded from the EES conceptual design because of projected cost limits.

4.5 SPECIAL CONSIDERATIONS FOR A SUN-SYNCHRONOUS ORBIT

The considerations for the baseline design and the enhanced design are the same for the sun-synchronous orbit case as for the 90° LEO.

Of the instruments listed in Table 3.2-2, three are candidates for a sun-synchronous orbit. Only one,NIREX, could be supported by the baseline design because the average bit rate of the other two would exceed 10 kbps by a large margin. SAMEX could be supported by the enhanced design. Astro/Atmos could not be supported by the enhanced design using a single ground station because the average data rate of 300 kbps would generate 1.3×10^{10} bits in 12 hours, exceeding the on-board storage capacity by a factor of four.

4.6 SPECIAL CONSIDERATIONS FOR A MOLNIYA ORBIT

A Molniya orbit is an elliptical orbit having geometry which results in the same part of the orbit occuring over the same point of the earth once each day. Depending on orbit parameters, the orbital period could be 24 or 12 hours. If the orbit were positioned so that apogee matched the longitude of a particular ground station, that ground station would have significantly long view periods. One or more dumps of stored data could be scheduled for each day, depending on orbit geometry. Because of the large ranges involved in supporting a Molniya orbit, any reasonable design for this orbit must include a high power transmitter and a high gain antenna for support of the return data link. The forward data link can utilize the high gain antenna for normal operations, but must be designed with a backup link operating at a low data rate to allow emergency communication to the spacecraft should the high gain antenna fail to be pointed correctly.

Of the instruments listed in Table 3.2-2, two are candidates for a Molniya orbit. IMAGE is not a true molniya orbit since it has a 90 degree inclination but its orbit altitude is too high to consider it to be a low earth polar orbit. The long contact times with a ground station and orbit altitude make it easier to deal with as a molniya type orbit. IMAGE has orbital requirements which may not be satisfied by the Delta launch vehicle. QUASAT has data rate requirements which cannot be satisfied by either of the EES designs.

SECTION 5 - MISSION COMMUNICATION USING EXISTING SN & GROUND STATION FACILITIES

Section 3 of this report described characteristics of the five classes of orbits to be supported by the EES. In addition, a strawman set of instruments was presented for use in assessing suitability of various alternatives for use with potential EES instruments. Capabilities of the existing NASA SN and ground stations to receive data from the EES designs and data rates in these orbits has been analyzed; the results of that analysis is presented in this section. In addition, the analysis considered SN and ground stations capability to receive data from the EES designs, but using data rates and orbit parameters for the strawman set of instruments, with the results of that analysis presented here as well. In this section it is assumed that data acquisition and data processing are performed using NASA resources, with subsequent delivery of the processed data to scientific investigators. Forward link performance was not analyzed because the EES designs were considered to provide adequate margins for minimum rates, and specific rates needed for the strawman instruments were not available. Alternative approaches for communicating with EES are discussed in Section 6.

5.1 COMMUNICATION USING THE SPACE NETWORK

Communication via the SN requires that the user spacecraft be visible to one or both TDRSs in orbit; also that the user spacecraft has sufficient sensitivity to receive signals from a TDRS and can generate sufficient radiated RF energy to provide an adequate return signal to a TDRS. Though phase-in of ATDRSS is scheduled to start in 1997, complete phase-out of TDRSS will not occur until fours years after the projected start of EES launches. Therefore, it is necessary to design for current TDRSS capabilities, ATDRSS capabilities should be considered as they become available. Requirements for satisfactory performance with the TDRSS were obtained from the SN Users' Guide, [Ref. 3].

5.1.1 Coverage Using the Space Network

Use of the TDRSS provides visibility of an EES in a LEO or sun-synchronous orbit for at least 85% of each orbit. The actual contact time achieved in practice may not equal this because of operational requirements of other spacecraft sharing use of the TDRSS, or other scheduling and spacecraft priority factors beyond the control of the EES. A detailed loading study would be required before firm support commitments would be made by NASA.

Of the five classes of orbits, the GEO orbit and a significant portion of the Molniya orbit cannot be supported by the current TDRSS. The ATDRSS should be able to communicate with most of the possible locations of a GEO orbit, and could support a Molniya orbit provided apogee were placed in an area viewable by one of the ATDRS, and provided the communications link had a positive margin over those parts of the orbit where contact were desired.

5.1.2 Communications Margins Using the Baseline Design with the Space Network

The return link for the baseline design EES will employ a 5 watt transmitter power and a shaped omni antenna. Assuming a spacecraft cable and diplexer loss of -3 dB results in an effective isotropic radiated power (EIRP) of 4 dBW. The link analysis has assumed a polarization loss of -0.5 dB, an RFI environment loss of -0.5 dB, and a -3.0 dB user spacecraft degradation loss, as these are typical values used by Code 531 when predicting user spacecraft support by TDRSS. User spacecraft pointing loss was assumed to be 0 dB because the baseline design will employ an omnidirectional antenna, and user incompatibility loss was assumed to be 0 dB because the design will employ a TDRSS-compatible transponder.

Using the values just discussed, the return link parameters for the baseline design are shown in the Table 5.1.2-1 spreadsheet. The GEO orbit is shown for completeness, but link parameters have been blanked out, as TDRSS cannot support that orbit. A spacecraft in a 500 km circular orbit (orbital inclination makes no difference for TDRSS support) transmitting a 1 kbps data rate, the net link margin using the TDRSS cross-support mode would be 3.5 dB. Support in the normal MA mode would not be possible as there would be insufficient EIRP to produce a positive margin in that mode, even for the 1 kbps return link data rate. Considering other orbits, the net margin for an 833 km circular orbit (a sun-synchronous case) would be 3.3 dB, and the net margin for a 12,000 km circular orbit would be 0.9 dB. The reason for the relatively small differences in net margin for these different orbits is that the maximum path length from the user spacecraft to TDRSS changes relatively little since the major contributor to the path length is the orbital height of the TDRS.

5.1.3 Communications Margins Using an Enhanced Design with the Space Network

The return link for this enhanced design EES concept will employ a 5 watt transmitter power and a planar array of 28 dB gain. Assuming a spacecraft cable and diplexer loss of -3 dB results in an EIRP of 38.5 dBW. The same assumptions have been made concerning RFI environment loss (-0.5 dB), user spacecraft degradation loss (-3 dB), and incompatibility loss (-0 dB) as were made for the baseline design. Since this design will employ a high gain planar array, a polarization loss of -3 dB has been included.

Using the values just discussed, the return link parameters for the enhanced design are shown in the Table 5.1.3-1 spreadsheet. The data rate of concern for this case is the playback rate of 1,250 kbps, as the real-time margin was shown to be viable using the lower EIRP of the baseline design. The margins shown are unacceptable, but only slightly negative indicating careful engineering and optimization of the communications system is needed. If about 3.6 dB can be added to the system than it will be able to handle the playback rate of 1,250 kbps for orbits out to 12,000 km. As for the baseline case, orbital inclination makes no difference for TDRSS support, and links are shown for orbits of 500 km, 833 km and 12,000 km circular orbits. The same figures would apply to elliptical orbits, provided the orbital altitude did not exceed 12,000 km.

Table 5.1.2-1. SN Return Link Margins, Baseline Design.

EES LINK CALCULATION
TDRSS Support

SPACECRAFT RETURN LINK	Orbit 1 (Geo)	Orb 2,3 (500 km)	Orb 2,3 (12k km)	Orbit 4 (S Sync)	Orbit 5 (Molniya)
Data Rate (kbps)	1.0	1.0	1.0	1.0	1.0
Carrier Frequency (MHz)	2287.5	2287.5	2287.5	2287.5	2287.5
Xmitter Power (watts)	5.0	5.0	5.0	5.0	5.0
Xmitter Power (dBW)	7.0	7.0	7.0	7.0	7.0
Modulation Loss (dB)	0.0	0.0	0.0	0.0	0.0
Cable/Diplexer Loss (dB)	-3.0	-3.0	-3.0	-3.0	-3.0
Xmit Ant Gain (dB)	19.0	0.0	0.0	0.0	19.0
EIRP (dBW)	23.0	4.0	4.0	4.0	23.0
TRANSMISSION MEDIUM					
Minimum Range (km)		35363.0	23863.0	35030.0	23863.0
Maximum Range (km)		44052.8	58939.9	44909.1	87664.9
Min Range Path Loss (dB)		-190.6	-187.2	-190.5	-187.2
Max Range Path Loss (dB)		-192.5	-195.0	-192.7	-198.5
User Pointing Loss (dB)	0.0	0.0	0.0	0.0	0.0
User Polarization Loss (dB)	-0.5	-0.5	-0.5	-0.5	-0.5
RFI Environment Loss (dB)	-0.5	-0.5	-0.5	-0.5	-0.5
User Incompatibility Loss (dB)	0.0	0.0	0.0	0.0	0.0
Min Range Total Loss (dB)		-191.6	-188.2	-191.5	-188.2
Max Range Total Loss (dB)		-193.5	-196.0	-193.7	-199.5
USER-TDRS CHARACTERISTICS					
Req'd SSA Signal (dBW)	-196.0	-196.0	-196.0	-196.0	-196.0
Req'd SMA Signal (dBW)	-186.0	-186.0	-186.0	-186.0	-186.0
Max Rcv'd Signal (dBW)		-187.6	-184.2	-187.5	-165.2
Min Rcv'd Signal (dBW)		-189.5	-192.1	-189.7	-176.5
User S/C Degredation (dB)	-3.0	-3.0	-3.0	-3.0	-3.0
User SSA Margin Max Range (dB)		3.5	0.9	3.3	16.5
User SMA Margin Max Range (dB)		-6.5	-9.1	-6.7	6.5
SPACECRAFT ORBIT					
User Perigee (km)	35784.0	500.0	12000.0	833.0	370.0
User Apogee (km)	35784.0	500.0	12000.0	833.0	40000.0
Minimum Range (km)		35363.0	23863.0	35030.0	23863.0
Maximum Range (km)		44052.8	58939.9	44909.1	87664.9
Earth radius at equator (km)	6378.1	6378.1	6378.1	6378.1	6378.1
User apogee above earth center (km)	42162.1	6878.1	18378.1	7211.1	46378.1
TDRS above equator (km)	35863.0	35863.0	35863.0	35863.0	35863.0
TDRS above earth center (km)	42241.1	42241.1	42241.1	42241.1	42241.1

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Table 5.1.3-1. SN Return Link Margins, Enhanced Design

EES LINK CALCULATION
TDRSS Support

SPACECRAFT RETURN LINK	Orbit 1 (Geo)	Orb 2,3 (500 km)	Orb 2,3 (12k km)	Orbit 4 (S Sync)	Orbit 5 (Molniya)
Data Rate (kbps)	1250.0	1250.0	1250.0	1250.0	1250.0
Carrier Frequency (MHz)	2287.5	2287.5	2287.5	2287.5	2287.5
Xmitter Power (watts)	5.0	5.0	5.0	5.0	5.0
Xmitter Power (dBW)	7.0	7.0	7.0	7.0	7.0
Modulation Loss (dB)	0.0	0.0	0.0	0.0	0.0
Cable/Diplexer Loss (dB)	-3.0	-3.0	-3.0	-3.0	-3.0
Xmit Ant Gain (dB)	19.0	28.0	28.0	28.0	19.0
EIRP (dBW)	23.0	32.0	32.0	32.0	23.0
TRANSMISSION MEDIUM					
Minimum Range (km)		35363.0	23863.0	35030.0	23863.0
Maximum Range (km)		44052.8	58939.9	44909.1	87664.9
Min Range Path Loss (dB)		-190.6	-187.2	-190.5	-187.2
Max Range Path Loss (dB)		-192.5	-195.0	-192.7	-198.5
User Pointing Loss (dB)	0.0	0.0	0.0	0.0	0.0
User Polarization Loss (dB)	-0.5	-0.5	-0.5	-0.5	-0.5
RFI Environment Loss (dB)	-3.0	-3.0	-3.0	-3.0	-3.0
User Incompatibility Loss (dB)	0.0	0.0	0.0	0.0	0.0
Min Range Total Loss (dB)		-194.1	-190.7	-194.0	-190.7
Max Range Total Loss (dB)		-196.0	-198.5	-196.2	-202.0
USER-TDRS CHARACTERISTICS					
Req'd SSA Signal (dBW)	-166.0	-166.0	-166.0	-166.0	-166.0
Req'd SMA Signal (dBW)					
Max Rcv'd Signal (dBW)		-162.1	-158.7	-162.0	-167.7
Min Rcv'd Signal (dBW)		-164.0	-166.6	-164.2	-179.0
User S/C Degredation (dB)	-3.0	-3.0	-3.0	-3.0	-3.0
User SSA Margin Max Range (dB)		-1.0	-3.6	-1.2	-16.0
User SMA Margin Max Range (dB)					
SPACECRAFT ORBIT					
User Perigee (km)	35784.0	500.0	12000.0	833.0	370.0
User Apogee (km)	35784.0	500.0	12000.0	833.0	40000.0
Minimum Range (km)		35363.0	23863.0	35030.0	23863.0
Maximum Range (km)		44052.8	58939.9	44909.1	87664.9
Earth radius at equator (km)	6378.1	6378.1	6378.1	6378.1	6378.1
User apogee above earth center (km)	42162.1	6878.1	18378.1	7211.1	46378.1
TDRS above equator (km)	35863.0	35863.0	35863.0	35863.0	35863.0
TDRS above earth center (km)	42241.1	42241.1	42241.1	42241.1	42241.1

5.1.4 Communications Margins Using the Strawman Instruments with the Space Network

Section 5.1.2 has shown that the baseline design can return a 1 kbps data rate with a comfortable margin. Section 5.1.3 has shown that the enhanced design could support the planned playback rate of 1250 kbps provided the communications system is optimized. This section includes discussion pertinent to the degree to which these designs could satisfy the strawman instruments.

Table 5.1.4-1 shows each of the instruments which could be supported by TDRSS. Communications margins for return of the peak data rate (assumed to be the real-time instrument output when operating in whatever operational mode would generate the highest data rate) are shown in this table. Since the average data rate from each of these instruments except one exceeds 10 kbps, the table lists parameters for only the enhanced design.

Of the 22 instruments having orbits supportable by TDRSS, 15 could be supported by the enhanced design. These include AEROS, AIM, Asteroseismology Explorer, EMAO, EXCAM, HECRE, HXRE, HXSIE, MELTER, Multiprobe Explorer Mission, NAE, NIREX, SAMEX, SOFE, and SpEx, which can be supported without reservation. ARTBE has a slightly negative margin which is unacceptable, but it could be supported if careful design and optimization of the communications system could bring the link margin positive.

One instrument, SHAPE, has an average data rate which can be supported by the enhanced design, but the 2,300 kbps real-time data rate exceeds the planned dump rate of 1,250 kbps. The TDRSS S-Band system can support such a data rate, but the link calculation shows a negative margin at the 2,300 kbps rate. By increasing the transmitter power to 28 watts the instrument could be supported without problem, this could be another version of the enhanced EES design.

Table 5.1.4-1. SN Return Link Calculation for Real-Time Rate, Strawman Instrument List

EES LINK CALCULATION TDRSS Support	AEROS	AIM	ARTBE	Astero	Ast/Alm	EMAO	EXCAM	HEASI	HECRE	HXRE	HXSIE
SPACECRAFT RETURN LINK											
Data Rate (kbps)	131.0	14.0	800.0	36.0	300.0	200.0	500.0	1000.0	102.0	20.0	48.0
Carrier Frequency (MHz)	2287.5	2287.5	2287.5	2287.5	2287.5	2287.5	2287.5	2287.5	2287.5	2287.5	2287.5
Xmitter Power (watts)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Xmitter Power (dBW)	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Modulation Loss (dB)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable/Diplexer Loss (dB)	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0
Xmit Ant Gain (dB)	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
EIRP (dBW)	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0
TRANSMISSION MEDIUM											
Minimum Range (km)	33863.0	23863.0	22863.0	35363.0	35363.0	31863.0	35363.0	35263.0	35363.0	35263.0	35163.0
Maximum Range (km)	47054.3	58939.9	60004.6	44052.8	44052.8	49849.4	44052.8	44335.3	44052.8	44335.3	44593.4
Min Range Path Loss (dB)	-190.2	-187.2	-186.8	-190.6	-190.6	-189.7	-190.6	-190.6	-190.6	-190.6	-190.6
Max Range Path Loss (dB)	-193.1	-195.0	-195.2	-192.5	-192.5	-193.6	-192.5	-192.6	-192.5	-192.6	-192.6
User Pointing Loss (dB)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
User Polarization Loss (dB)	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0
RFI Environment Loss (dB)	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
User Incompatibility Loss (dB)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Min Range Total Loss (dB)	-193.7	-190.7	-190.3	-194.1	-194.1	-193.2	-194.1	-194.1	-194.1	-194.1	-194.1
Max Range Total Loss (dB)	-196.6	-198.5	-198.7	-196.0	-196.0	-197.1	-196.0	-196.1	-196.0	-196.1	-196.1
USER-TDRS CHARACTERISTICS											
Req'd SSA Signal (dBW)	-176.0	-185.0	-169.0	-181.5	-172.0	-174.0	-170.5	-168.0	-177.0	-184.0	-180.0
Req'd SMA Signal (dBW)		-175.0		-171.5						-174.0	-170.0
Max Rcv'd Signal (dBW)	-161.7	-158.7	-158.3	-162.1	-162.1	-161.2	-162.1	-162.1	-162.1	-162.1	-162.1
Min Rcv'd Signal (dBW)	-164.6	-166.6	-166.7	-164.0	-164.0	-165.1	-164.0	-164.1	-164.0	-164.1	-164.1
User S/C Degredation (dB)	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0
User SSA Margin Max Range (dB)	8.4	15.4	-0.7	14.5	5.0	5.9	3.5	0.9	10.0	16.9	12.9
User SMA Margin Max Range (dB)		5.4		4.5						6.9	2.9
SPACECRAFT ORBIT											
User Perigee (km)	600.0	300.0	1000.0	500.0	500.0	150.0	500.0	600.0	500.0	600.0	700.0
User Apogee (km)	2000.0	12000.0	13000.0	500.0	500.0	4000.0	500.0	600.0	500.0	600.0	700.0
Minimum Range (km)	33863.0	23863.0	22863.0	35363.0	35363.0	31863.0	35363.0	35263.0	35363.0	35263.0	35163.0
Maximum Range (km)	47054.3	58939.9	60004.6	44052.8	44052.8	49849.4	44052.8	44335.3	44052.8	44335.3	44593.4
Earth radius at equator (km)	6378.1	6378.1	6378.1	6378.1	6378.1	6378.1	6378.1	6378.1	6378.1	6378.1	6378.1
User apogee above earth center (km)	8378.1	18378.1	19378.1	6878.1	6878.1	10378.1	6878.1	6978.1	6878.1	6978.1	7078.1
TDRS above equator (km)	35863.0	35863.0	35863.0	35863.0	35863.0	35863.0	35863.0	35863.0	35863.0	35863.0	35863.0
TDRS above earth center (km)	42241.1	42241.1	42241.1	42241.1	42241.1	42241.1	42241.1	42241.1	42241.1	42241.1	42241.1

EES LINK CALCULATION TDRSS Support	LUX	Lyman	MELTER	Micro/Ex	Multipro	NAE	NIREX	SAMEX	SHAPE	SOFE	SpEx
SPACECRAFT RETURN LINK											
Data Rate (kbps)	120.0	48000.0	12.0	800.0	50.0	15.0	4.0	53.0	2300.0	25.0	64.0
Carrier Frequency (MHz)	2287.5	2287.5	2287.5	2287.5	2287.5	2287.5	2287.5	2287.5	2287.5	2287.5	2287.5
Xmitter Power (watts)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Xmitter Power (dBW)	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Modulation Loss (dB)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable/Diplexer Loss (dB)	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0
Xmit Ant Gain (dB)	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
EIRP (dBW)	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0
TRANSMISSION MEDIUM											
Minimum Range (km)	35363.0	35363.0	35203.0	34363.0	20863.0	35413.0	35163.0	33713.0	35363.0	35363.0	35363.0
Maximum Range (km)	44052.8	44052.8	44492.6	46224.6	62114.4	43899.5	44593.4	47287.8	44052.8	44052.8	44052.8
Min Range Path Loss (dB)	-190.6	-190.6	-190.6	-190.4	-186.0	-190.6	-190.6	-190.2	-190.6	-190.6	-190.6
Max Range Path Loss (dB)	-192.5	-192.5	-192.6	-192.9	-195.5	-192.5	-192.6	-193.1	-192.5	-192.5	-192.5
User Pointing Loss (dB)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
User Polarization Loss (dB)	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0
RFI Environment Loss (dB)	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
User Incompatibility Loss (dB)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Min Range Total Loss (dB)	-194.1	-194.1	-194.1	-193.9	-189.5	-194.1	-194.1	-193.7	-194.1	-194.1	-194.1
Max Range Total Loss (dB)	-196.0	-196.0	-196.1	-196.4	-199.0	-196.0	-196.1	-196.6	-196.0	-196.0	-196.0
USER-TDRS CHARACTERISTICS											
Req'd SSA Signal (dBW)	-176.0	-163.0	-185.5	-170.0	-180.0	-184.5	-189.5	-180.0	-163.0	-182.5	-179.0
Req'd SMA Signal (dBW)			-175.5		-170.0	-174.5	-179.5			-172.5	
Max Rcv'd Signal (dBW)	-162.1	-162.1	-162.1	-161.9	-157.5	-162.1	-162.1	-161.7	-162.1	-162.1	-162.1
Min Rcv'd Signal (dBW)	-164.0	-164.0	-164.1	-164.4	-167.0	-164.0	-164.1	-164.6	-164.0	-164.0	-164.0
User S/C Degredation (dB)	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0
User SSA Margin Max Range (dB)	9.0	-4.0	18.4	2.6	10.0	17.5	22.4	12.4	-4.0	15.5	12.0
User SMA Margin Max Range (dB)			8.4		-0.0	7.5	12.4			5.5	
SPACECRAFT ORBIT											
User Perigee (km)	500.0	500.0	660.0	350.0	500.0	450.0	700.0	2150.0	500.0	500.0	500.0
User Apogee (km)	500.0	500.0	660.0	1500.0	15000.0	450.0	700.0	2150.0	500.0	500.0	500.0
Minimum Range (km)	35363.0	35363.0	35203.0	34363.0	20863.0	35413.0	35163.0	33713.0	35363.0	35363.0	35363.0
Maximum Range (km)	44052.8	44052.8	44492.6	46224.6	62114.4	43899.5	44593.4	47287.8	44052.8	44052.8	44052.8
Earth radius at equator (km)	6378.1	6378.1	6378.1	6378.1	6378.1	6378.1	6378.1	6378.1	6378.1	6378.1	6378.1
User apogee above earth center (km)	6878.1	6878.1	7038.1	7878.1	21378.1	6828.1	7078.1	8528.1	6878.1	6878.1	6878.1
TDRS above equator (km)	35863.0	35863.0	35863.0	35863.0	35863.0	35863.0	35863.0	35863.0	35863.0	35863.0	35863.0
TDRS above earth center (km)	42241.1	42241.1	42241.1	42241.1	42241.1	42241.1	42241.1	42241.1	42241.1	42241.1	42241.1

Note: A Req'd SSA Signal of -163 dBW is the req'mt for the max SSA data rate

Four of the instruments, Astro/Atmos Spect. Explorer, HEASI, LUX, and Microphysics Explorer have average data rates which significantly exceed the planned average data rate of the enhanced design. With peak data rates of 300 kbps, 1,000 kbps, 120 kbps and 800 kbps, respectively, the peak data rate could be returned via TDRSS, even though the averages exceed 100 kbps. Thus, return of real-time data from these instruments could be supported for limited periods of time, but return of all data generated would require much more frequent data dumps than planned, and perhaps more frequent contacts than could be supported by TDRSS unless the spacecraft had a very high priority.

One of the instruments, Lyman, has a peak data rate of 48,000 kbps with an average rate of 24 kbps. The real-time rate of this instrument cannot be supported by an S-Band system, but the average rate could easily be supported by the enhanced design. The 'Required SSA Signal' at the TDRS is shown on Table 5.1.4-1 as being -163 dBW, this is the required signal level for a 3 Mbps (not 48 Mbps) data rate which is the maximum rate the SSA can handle.

5.2 COMMUNICATION USING GROUND STATIONS

NASA maintains very few ground facilities, compared with those maintained before the TDRSS became operational. However, the remaining ground stations are organized into three networks: ground stations, operated by GSFC; WPS, also operated by GSFC; and the DSN, operated by the Jet Propulsion Laboratory (JPL). All of these facilities support the NASA standard S-Band transponders with a 240/221 transponding ratio. Other carrier frequencies and system capabilities are supported at individual facilities.

5.2.1 Communications Margins Using the Baseline Design with the Ground Stations

This EIRP radiated by the EES baseline design will be 4 dBW, the same as was discussed in Section 5.1.2. The major differences between this situation and support via TDRSS are the G/T of the receiving antenna and the path length over which the data must be transmitted. This means that much higher data rates can be transmitted with the same spacecraft design. The penalty is that a ground station can see the spacecraft during only a small percentage of each orbit. For the baseline design, a shaped omni antenna has been baselined for each orbit class.

Using the values just discussed, the return link parameters for the baseline design are shown in the Table 5.2.1-1 spreadsheet. The data rate shown is the baseline data dump rate of 650 kbps. All cases show positive margins which are acceptable.

5.2.2 Communications Margins Using an Enhanced Design with Ground Stations

This EES enhanced design has been baselined for use with a ground station only for orbits above 12,000 km. Table 5.2.2-1 is a spreadsheet which has been constructed using all five classes of orbits, but using spacecraft parameters of a 5 watt transmitter and a shaped omni antenna. This shows what could be used as a backup to transmission via TDRSS should the high gain antenna on the spacecraft suffer an outage. In the case of the 12,000 km orbit, the margin would be negative if the antenna fails. For 12,000 km orbits, having a higher power transmitter with a 5 watt transmitter as backup would allow more room for failure of a component, since both transmitter and antenna would have to fail for the link margin to be negative.

The geosynchronous and the Molniya orbits have been baselined for EES with a 5 watt transmitter and a 19 dB antenna, and a shaped omni as the redundant antenna. The 19 dB antenna would allow an adequate signal margin, but the shaped omni would not provide an adequate signal margin to continue normal operations if the high gain antenna failed. A ground station with higher G/T performance could be used, but it may not be possible to arrange long-term support by such a system unless the EES Project purchased it.

Table 5.2.1-1. Ground Station Return Link Margins, Baseline Design

EES LINK CALCULATION
Direct to Ground, not via TDRSS

	Orbit 1 (Geo)	Orb 2,3 (500 km)	Orb 2,3 (12k km)	Orbit 4 (S Sync)	Orbit 5 (Molniya)
SPACECRAFT RETURN LINK					
Data Rate (kbps)	650.0	650.0	650.0	650.0	650.0
Carrier Frequency (MHz)	2287.5	2287.5	2287.5	2287.5	2287.5
Xmitter Power (watts)	5.0	5.0	5.0	5.0	5.0
Xmitter Power (dBm)	37.0	37.0	37.0	37.0	37.0
Modulation Loss (dB)	0.0	0.0	0.0	0.0	0.0
Cable/Diplexer Loss (dB)	-3.0	-3.0	-3.0	-3.0	-3.0
Xmit Ant Gain (dB)	19.0	0.0	0.0	0.0	19.0
EIRP (dBm)	53.0	34.0	34.0	34.0	53.0
TRANSMISSION MEDIUM					
Minimum Range (km)	35784.0	500.0	12000.0	833.0	370.0
Horizon Mask Range (km)	40053.9	1694.5	16159.5	2433.6	44837.6
Atmospheric Atten (dB)	0.0	0.0	0.0	0.0	0.0
Rain Atten (dB)	0.0	0.0	0.0	0.0	0.0
User Pointing Loss (dB)	0.0	0.0	0.0	0.0	0.0
User Polarization Loss (dB)	0.0	0.0	0.0	0.0	0.0
Overhead Path Loss (dB)	-190.7	-153.6	-181.2	-158.1	-151.0
Horiz Mask Path Loss (dB)	-191.7	-164.2	-183.8	-167.4	-192.7
USER-GND SYST CHARACTERISTICS					
Gnd Ant Diameter (ft)	30	30	30	30	30
Gnd Ant Gain (dB)	44.1	44.1	44.1	44.1	44.1
Overhead Rcvd Pwr (dBm)	-93.6	-75.5	-103.1	-79.9	-53.9
Horiz Mask Rcvd Pwr (dBm)	-94.6	-86.1	-105.7	-89.2	-95.6
System Noise Temp (K)	150.0	150.0	150.0	150.0	150.0
System G/T (dB/K)	22.4	22.4	22.4	22.4	22.4
Overhead Channel SNR (Eb/No)	25.1	43.2	15.6	38.8	64.8
Horiz Mask Channel SNR (Eb/No)	24.1	32.6	13.0	29.5	23.2
Req'd SNR (Eb/No)	9.6	9.6	9.6	9.6	9.6
User S/C Degredation (dB)	-3.0	-3.0	-3.0	-3.0	-3.0
Overhead Signal Margin (dB)	12.5	30.6	3.0	26.2	52.2
Horiz Mask Signal Margin (dB)	11.5	20.0	0.4	16.9	10.6
SPACECRAFT ORBIT PARAMETERS					
Perigee (km)	35784.0	500.0	12000.0	833.0	370.0
Apogee (km)	35784.0	500.0	12000.0	833.0	40000.0
Horizon Mask (deg)	15.0	10.0	10.0	10.0	10.0
Minimum Range (km)	35784.0	500.0	12000.0	833.0	370.0
Maximum Range (km)	40053.9	1694.5	16159.5	2433.6	44837.6
Earth Radius at 35 Lat	6370.0	6370.0	6370.0	6370.0	6370.0
Re + Perigee	42154.0	6870.0	18370.0	7203.0	46370.0

Table 5.2.2-1. Ground Station Return Link Margins, Enhanced Design Contingency

EES LINK CALCULATION
Direct to Ground, not via TDRSS

SPACECRAFT RETURN LINK	Orbit 1 (Geo)	Orb 2,3 (500 km)	Orb 2,3 (12k km)	Orbit 4 (S Sync)	Orbit 5 (Molniya)
Data Rate (kbps)	1250.0	1250.0	1250.0	1250.0	1250.0
Carrier Frequency (MHz)	2287.5	2287.5	2287.5	2287.5	2287.5
Xmitter Power (watts)	5.0	5.0	5.0	5.0	5.0
Xmitter Power (dBm)	37.0	37.0	37.0	37.0	37.0
Modulation Loss (dB)	0.0	0.0	0.0	0.0	0.0
Cable/Diplexer Loss (dB)	-3.0	-3.0	-3.0	-3.0	-3.0
Xmit Ant Gain (dB)	0.0	0.0	0.0	0.0	0.0
EIRP (dBm)	34.0	34.0	34.0	34.0	34.0
TRANSMISSION MEDIUM					
Minimum Range (km)	35784.0	500.0	12000.0	833.0	370.0
Horizon Mask Range (km)	40053.9	1694.5	16159.5	2433.6	44837.6
Atmospheric Atten (dB)	0.0	0.0	0.0	0.0	0.0
Rain Atten (dB)	0.0	0.0	0.0	0.0	0.0
User Pointing Loss (dB)	0.0	0.0	0.0	0.0	0.0
User Polarization Loss (dB)	0.0	0.0	0.0	0.0	0.0
Overhead Path Loss (dB)	-190.7	-153.6	-181.2	-158.1	-151.0
Horiz Mask Path Loss (dB)	-191.7	-164.2	-183.8	-167.4	-192.7
USER-GND SYST CHARACTERISTICS					
Gnd Ant Diameter (ft)	30	30	30	30	30
Gnd Ant Gain (dB)	44.1	44.1	44.1	44.1	44.1
Overhead Rcvd Pwr (dBm)	-112.6	-75.5	-103.1	-79.9	-72.9
Horiz Mask Rcvd Pwr (dBm)	-113.6	-86.1	-105.7	-89.2	-114.6
System Noise Temp (K)	150.0	150.0	150.0	150.0	150.0
System G/T (dB/K)	22.4	22.4	22.4	22.4	22.4
Overhead Channel SNR (Eb/No)	3.3	40.4	12.8	35.9	43.0
Horiz Mask Channel SNR (Eb/No)	2.3	29.8	10.2	26.6	1.3
Req'd SNR (Eb/No)	9.6	9.6	9.6	9.6	9.6
User S/C Degredation (dB)	-3.0	-3.0	-3.0	-3.0	-3.0
Overhead Signal Margin (dB)	-9.3	27.8	0.2	23.3	30.4
Horiz Mask Signal Margin (dB)	-10.3	17.2	-2.4	14.0	-11.3
SPACECRAFT ORBIT PARAMETERS					
Perigee (km)	35784.0	500.0	12000.0	833.0	370.0
Apogee (km)	35784.0	500.0	12000.0	833.0	40000.0
Horizon Mask (deg)	15.0	10.0	10.0	10.0	10.0
Minimum Range (km)	35784.0	500.0	12000.0	833.0	370.0
Maximum Range (km)	40053.9	1694.5	16159.5	2433.6	44837.6
Earth Radius at 35 Lat	6370.0	6370.0	6370.0	6370.0	6370.0
Re + Perigee	42154.0	6870.0	18370.0	7203.0	46370.0

5.2.3 Communications Margins Using the Strawman Instruments with Ground Stations

Support of most of the strawman instruments was discussed in Section 5.1.4. Signal margins for those instruments would all be more generous using a ground station, but contact times could not be scheduled with the same flexibility as they could with TDRSS. This section discusses the strawman instruments that are listed with apogees significantly exceeding 12,000 km.

QUASAT, with a data rate of 128 Mbps, is listed with the others, but that data rate cannot be supported by an S-Band system, nor does an instrument generating that data rate 100% of the time make a logical instrument for a "low cost" program.

Table 5.2.3-1 lists the real-time data rate for each of the instruments, except that SYNOP has been changed to 40 kbps since the 40 bps rate listed in the input material appeared to be a mistake. (If it really should be 40 bps, signal margins would be significantly better than those listed.) Real-time data could be transmitted for IMAGE and SYNOP using the 5 watt transmitter and a 19 dB antenna throughout the orbits. From reading the proposals for both IMAGE and SYNOP, it appeared that both were designed for real-time operations. SYNOP in particular will perform IUE type operations. A shaped omni antenna would support this and would be more useful to IUE type operations. For IMAGE a lower gain less directional antenna might be appropriate as well. Table 5.2.3-2 lists each instrument with the enhanced design playback rate of 1,250 kbps. The design would produce a positive signal margin for both IMAGE and SYNOP.

5.3 OPERATIONAL SCENARIOS USING THE SPACE NETWORK, GROUND STATIONS, OR A COMBINATION OF BOTH

A spacecraft using a high gain antenna must be adequately stabilized to allow pointing the antenna at either a TDRS or the supporting ground station. As a backup, the spacecraft should have an omnidirectional antenna which will support a limited rate of both forward and return data links in order to recover spacecraft stabilization and resume use of the high gain antenna.

The EES baseline design incorporates operation via TDRSS for return of low rate real-time data and low rate forward link. High rate dump would be accomplished via a supporting ground station. The link margins would support such an operation, and the operational scenarios employed would be very similar to the COBE operation. It should be noted, though, that the COBE data rates are lower than proposed for the strawman instruments. This scenario becomes more difficult to implement as the data rates increase.

Communication via TDRSS permits a more flexible scheduling of contact times for support of real-time operations, but data rates via TDRSS for the EES baseline design would be too low to allow real-time interaction with the spacecraft. The EES enhanced design could be employed for such an operation. However, using TDRSS for real-time operations would require either very limited scheduling flexibility (many schedule requests would be rejected) or that the actual time of the real-time operation can be shifted to agree with the TDRSS schedule.

Operational scenarios for support of a Molniya orbit have been considered only superficially, as the plans for use of this orbit had not been fully developed at the time of this report. Support of spacecraft in elliptical orbits having an apogee of less than 12,000 km should not be significantly different from support of other LEO spacecraft.

In summary, the EES designs appear to provide reasonable flexibility in supporting various instruments. The specific operational scenarios to be employed can be examined when more specific candidate instruments are selected, as the operational scenario should be tailored to the science operations required.

Table 5.2.3-1. Ground Station Return Link Margins, Strawman Instruments (Real-Time)

EES LINK CALCULATION
Direct to Ground, not via TDRSS

	IMAGE	QUASAT	SYNOP
SPACECRAFT RETURN LINK	Real-Time Data Rates		
Data Rate (kbps)	90.0	128000.0	40.0
Carrier Frequency (MHz)	2287.5	2287.5	2287.5
Xmitter Power (watts)	5.0	5.0	5.0
Xmitter Power (dBm)	37.0	37.0	37.0
Modulation Loss (dB)	0.0	0.0	0.0
Cable/Diplexer Loss (dB)	-3.0	-3.0	-3.0
Xmit Ant Gain (dB)	19.0	19.0	19.0
EIRP (dBm)	53.0	53.0	53.0
TRANSMISSION MEDIUM			
Minimum Range (km)	19200.0	18900.0	35871.0
Horizon Mask Range (km)	68983.7	34272.0	40666.4
Atmospheric Atten (dB)	0.0	0.0	0.0
Rain Atten (dB)	0.0	0.0	0.0
User Pointing Loss (dB)	0.0	0.0	0.0
User Polarization Loss (dB)	0.0	0.0	0.0
Overhead Path Loss (dB)	-185.3	-185.2	-190.7
Horiz Mask Path Loss (dB)	-196.4	-190.3	-191.8
USER-GND SYST CHARACTERISTICS			
Gnd Ant Diameter (ft)	30	30	30
Gnd Ant Gain (dB)	44.1	44.1	44.1
Overhead Rcvd Pwr (dBm)	-88.2	-88.0	-93.6
Horiz Mask Rcvd Pwr (dBm)	-99.3	-93.2	-94.7
System Noise Temp (K)	150.0	150.0	150.0
System G/T (dB/K)	22.4	22.4	22.4
Overhead Channel SNR (Eb/No)	39.1	7.7	37.2
Horiz Mask Channel SNR (Eb/No)	28.0	2.6	36.1
Req'd SNR (Eb/No)	9.6	9.6	9.6
User S/C Degredation (dB)	-3.0	-3.0	-3.0
Overhead Signal Margin (dB)	26.5	-4.9	24.6
Horiz Mask Signal Margin (dB)	15.4	-10.0	23.5
SPACECRAFT ORBIT PARAMETERS			
Perigee (km)	19200.0	18900.0	35871.0
Apogee (km)	64000.0	29560.0	35871.0
Horizon Mask (deg)	10.0	10.0	10.0
Minimum Range (km)	19200.0	18900.0	35871.0
Maximum Range (km)	68983.7	34272.0	40666.4
Earth Radius at 35 Lat	6370.0	6370.0	6370.0
Re + Perigee	70370.0	35930.0	42241.0

Table 5.2.3-2. Ground Station Return Link Margins, Strawman Instruments (Data-Dump)

EES LINK CALCULATION
Direct to Ground, not via TDRSS

	IMAGE	QUASAT	SYNOP
SPACECRAFT RETURN LINK	Data-Dump Data Rates		
Data Rate (kbps)	1250.0	128004.0	1250.0
Carrier Frequency (MHz)	2287.5	2287.5	2287.5
Xmitter Power (watts)	5.0	5.0	5.0
Xmitter Power (dBm)	37.0	37.0	37.0
Modulation Loss (dB)	0.0	0.0	0.0
Cable/Diplexer Loss (dB)	-3.0	-3.0	-3.0
Xmit Ant Gain (dB)	19.0	19.0	19.0
EIRP (dBm)	53.0	53.0	53.0
TRANSMISSION MEDIUM			
Minimum Range (km)	19200.0	18900.0	35871.0
Horizon Mask Range (km)	68983.7	34272.0	40666.4
Atmospheric Atten (dB)	0.0	0.0	0.0
Rain Atten (dB)	0.0	0.0	0.0
User Pointing Loss (dB)	0.0	0.0	0.0
User Polarization Loss (dB)	0.0	0.0	0.0
Overhead Path Loss (dB)	-185.3	-185.2	-190.7
Horiz Mask Path Loss (dB)	-196.4	-190.3	-191.8
USER-GND SYST CHARACTERISTICS			
Gnd Ant Diameter (ft)	30	30	30
Gnd Ant Gain (dB)	44.1	44.1	44.1
Overhead Rcvd Pwr (dBm)	-88.2	-88.0	-93.6
Horiz Mask Rcvd Pwr (dBm)	-99.3	-93.2	-94.7
System Noise Temp (K)	150.0	150.0	150.0
System G/T (dB/K)	22.4	22.4	22.4
Overhead Channel SNR (Eb/No)	27.7	7.7	22.3
Horiz Mask Channel SNR (Eb/No)	16.6	2.6	21.2
Req'd SNR (Eb/No)	9.6	9.6	9.6
User S/C Degredation (dB)	-3.0	-3.0	-3.0
Overhead Signal Margin (dB)	15.1	-4.9	9.7
Horiz Mask Signal Margin (dB)	4.0	-10.0	8.6
SPACECRAFT ORBIT PARAMETERS			
Perigee (km)	19200.0	18900.0	35871.0
Apogee (km)	64000.0	29560.0	35871.0
Horizon Mask (deg)	10.0	10.0	10.0
Minimum Range (km)	19200.0	18900.0	35871.0
Maximum Range (km)	68983.7	34272.0	40666.4
Earth Radius at 35 Lat	6370.0	6370.0	6370.0
Re + Perigee	70370.0	35930.0	42241.0

6.0 ALTERNATIVE COMMUNICATION APPROACHES

Section 4 demonstrated that EES could be properly supported by either the SN or the ground stations, with the exception that the ground stations, as presently planned, will be unable to cover spacecraft in low inclination orbits. This section examines the availability of other non-NASA resources to deal with this problem and also to enhance coverage of polar orbiters. In addition, transportable ground stations, a dedicated equatorial station for the EES, and data collection and processing at the Principal Investigator's facility are considered.

6.1 USE OF OTHER GROUND STATIONS

NASA does not presently plan to operate any ground stations in high latitudes. As a result, NASA may have difficulty providing frequent contacts with polar orbiters. For example, data collection from the AEROS instrument may be needed at least every 6 hours to permit near-real-time changes in science operations, including related aircraft operations. If NASA is obliged to provide this level of service and is unable to provide the needed resources, the use of non-NASA ground stations will be necessary. The non-NASA ground stations considered by this study are not fully compatible with NASA interface standards and are likely to require upgrades in order to satisfy EES requirements.

6.1.1 Use of US Resources

NASA operates a Networks Test and Training Facility (NTTF) at GSFC which has a 9 meter antenna with a complete ground system that can support S-Band. They have supported operations in the past and could conceivably do it again, but their charter is test bed support only and any operations would have to be negotiated with code 530. Currently, the NTTF has two vacant pads on which antennas could be placed. One of the advantages of using NTTF is the ease of routing the data to the processing facility at GSFC [Ref. 9].

NASA's White Sands Ground Terminal (WSGT) is currently building a second TDRSS receiving station and would be a good site for a ground station based on the fact that staffing and operations are already there. However, there is the possibility that the S-Band would interfere with normal TDRSS communications.

The US Air Force operates a network of tracking stations that could provide coverage for EES. Each of these stations has the potential to provide needed coverage, but experience has shown that the stations are busy conducting USAF/DOD operations and may not be available to support EES. These stations are not presently fully compatible with NASA communications standards, but the Air Force may be receptive to the idea of achieving compatibility. NASA presently uses the Air Force network to provide Shuttle support and has also provided launch support for the Geostationary Environmental Satellite (GOES) project from the Seychelle Islands station.

It is worth noting the USAF stations at Ascension Island and Diego Garcia are separated by approximately 90 degrees of longitude. This geometry is potentially useful in the AEROS case, as two stations separated by 90 degrees will be able to communicate with a polar orbiter at approximately 6-hour intervals.

The National Oceanic and Atmospheric Administration (NOAA) operates tracking stations near Fairbanks, Alaska and Wallops Island, Virginia. The Fairbanks station is well located to collect data from polar orbiters and should require minimal upgrades to provide compatibility with NASA S-Band standards. NOAA uses the Fairbanks and Wallops stations to collect data from its own polar orbiters, and the same approach presumably would be satisfactory for NASA. NOAA also has communication satellite capabilities that could conceivably be used to transport EES data.

6.1.2 Foreign Resources

High latitude territories in the Western Hemisphere could be used as a base for EES support for polar orbiters.

The European Space Agency (ESA) operates a network of stations around the world. Each of these stations has S-Band capabilities that are nearly compatible with NASA standards. However existing data communications resources are limited in some cases. The use of ESA stations would probably be less expensive than the creation and use of new NASA facilities.

6.2 TRANSPORTABLE GROUND STATION

The Wallops Flight Facility is developing two advanced transportable ground stations (TGS) which are intended to provide S-Band tracking, telemetry, and command (TT&C) capabilities in a variety of situations, including the following:

- Communication with sounding rockets during ascent
- Communication with spacecraft in Earth orbit
- Combined TT&C/Science operations at an investigator's facility
- Stand-in for 9 meter antenna during depot level maintenance

Ranging is not a capability of the TGS. It was omitted to keep cost and complexity at a minimum.

The transportable nature of these stations permits them to be relocated from site to site as needs dictate. Figure 6.2-1 provides a system-level block diagram of a TGS.

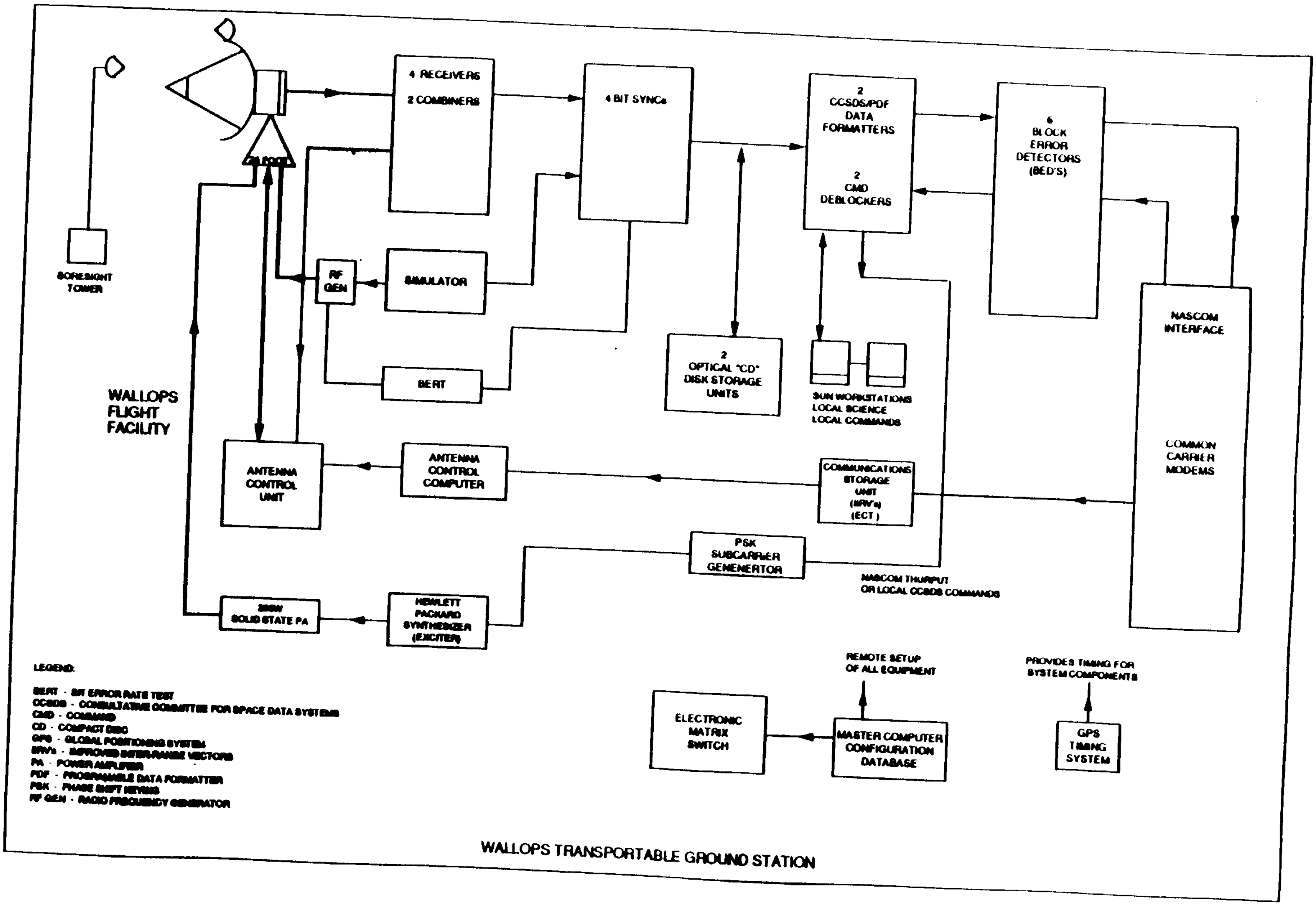


Figure 6.2-1. TGS Block Diagram

When prepared for shipping, each TGS is packaged in 2 standard shipping containers (approximately 8 X 8 X 20 feet and 8 X 8 X 40 feet) and a 40 foot trailer. The containers house antenna components, and the trailer houses electronic instrumentation. At the operating location a team of 3 technicians performs assembly, checkout, and calibration in a nominal 2 week period. Facility requirements include a concrete pad for the antenna and electric service (208 volts 3-phase, 100 amps per leg). During operations a team of two (one technician and one computer operator) will probably be needed for operations support and maintenance. However, the highly automated design of the TGS may permit unattended operation should that be required.

6.2.1 RF System Functionality and Performance

The planned functionality and performance of the TGS RF system is summarized in Table 6.2-1.

Table 6.2-1. RF System Capabilities

Function	Features and Performance
Antenna	8 meter reflector, feed at prime focus, anti-backlash electric drive, azimuth-over-elevation pedestal on 18 foot riser; maximum slew rate 20 degrees/sec; maximum acceleration 20 degrees/sec/sec; autotrack or computer control of pedestal angles; optimizing algorithm for overhead pass geometry; operational to -8 degrees elevation
Receiving	G/T > 21 dB/K @ 60 degrees elevation polarization diversity (LCP and RCP); selectable frequency band (2200-2300 MHz or 2300-2400 MHz)
Transmitting	EIRP > +93 dBm; selectable polarization (LCP or RCP); selectable frequency (2025-2120 MHz)
Tracking	Angle tracking only; Accuracy 0.05 degrees RMS per axis, 3 sigma Output format - Minimum Delay Data Format
Ephemeris	IIRV or NORAD

6.2.2 Data System Functionality and Performance

TGS data handling is compatible with CCSDS recommendations and includes provision for command management, command stream generation, downlink stream synchronization, virtual channel extraction and display, and tracking data formatting. A data system operator plans and schedules near-term operations, then sets up TGS hardware and software systems to automatically perform a sequence of spacecraft contacts over a period which may extend for several days. Spacecraft view periods and antenna steering angles are forecast using target vectors from NASA or North American Defence (NORAD), proven propagation algorithms, and a 5th harmonic model of the Earth's gravity field.

During operations the data system uplinks preplanned command sets and processes tracking, telemetry, and science data. Magnetic disk and/or magneto-optical disk/tape are used for data storage. External data communications are supported using NASCOM protocols at data rates up to 1.544 Mbps.

The data system continuously monitors and controls all TGS systems. Monitor and control modes include alignment, calibration, self-test, and operations. The system uses a boresight source and astronomical targets for automatic test and calibration prior to tracking operations. Performance and data quality checks are performed concurrently with operations.

A "disciplined" rubidium frequency standard provides reference signals with short-term stability on the order of 1E-12. Global Positioning System (GPS) equipment uses the GPS Coarse/Acquisition Code to provide timing signals and determines the operating location of the TGS.

6.3 ALLOCATION OF FUNCTIONS

Table 6.3-1 shows the primary mission operations and data handling functions that must be performed in order to properly support space missions. A portion of these functions has traditionally been allocated to the ground stations, and the remainder have been the responsibility of central data processing facilities. This section discusses some non-traditional allocation of functions that could be advantageous for EES missions.

Table 6.3-1. Ground Mission Operations and Data Handling Activities

Data Type	RF Communications	Interface Processing	Data Analysis	Operations Control	Data Storage
Science data processing	Receive serial data	Construct data set	Analyze data set	Develop science command requirements	Archive data sets
Engineering telemetry data	Receive serial data	Decommuntate and display data	Analyze data off-line and perform trend analysis	Monitor health and safety	Archive critical engineering data
Command processing	Transmit serial commands	Build command load	Select command sequence	Integrate command requirements	Archive command history
Tracking	Measure position, velocity	Update measurement data base	Update ephemeris	Develop tracking command requirements	Archive ephemeris data

Performing certain scientific data acquisition and data processing at an investigator's facility offers important advantages for missions, which require prompt access to their data, for example, a camera planned to photograph a transient event such as a comet, which may fade from view in a few days. The comet camera must have real-time access to its data stream, so that a rapid assessment of data quality can be made, and exposure or observing techniques can be refined quickly.

6.3.1 Possible Configurations

Two configurations were considered to clarify the primary trade-offs involved in performing the functions contained in Table 6.3-1. When an actual system design is completed and approved, it may well use an intermediate approach between the extremes considered here.

A direct interface configuration would be designed to provide investigators with access to and control over the uplink or downlink. This could be accomplished either by locating a transportable ground station at the investigator's facility or by using long distance ground station at the investigator's facility or by using long distance data lines or commercial communication satellites to link his facility to remote ground stations.

Spacecraft in moderate inclination orbits may pass near the investigator's facility, depending on its latitude, and would permit direct data acquisition by the user. Spacecraft in polar orbit will always pass over the facility, regardless of its location.

If NASA adopts a uniform data acquisition interface for the user, that interface must clearly provide remote data acquisition and the use of long distance data communication lines. The current planning of the EES program, however, does not seem to necessitate a uniform approach. In the absence of such a requirement, it appears reasonable to consider the benefits of user ground stations.

6.3.2 Acquisition and Processing of Science Data

Science data acquisition could be accomplished using an inexpensive ground station limited to reception. Such a ground station would cost approximately $0.6 million (excluding level-0 processing) to build [Ref. 10], could be designed for unattended operation, and would provide an investigator with direct access to his data. The investigator would be the sole recipient of the downlink data and would necessarily be responsible for distributing, processing, and archiving the entire mission data set. The investigator would submit science command requests to a NASA control center.

This approach would concentrate the science effort in a single location, minimize the use of data lines, and probably be cost-effective. However, if the spacecraft downlink data contains multiplexed science and engineering data, as seems likely, the investigator will either have to assume the responsibility for analyzing the engineering data or forwarding it to the responsible party, presumably a NASA control center. Forwarding the data is perfectly feasible and could be accomplished routinely be mailing tapes of accumulated engineering data. If immediate examination of the data were needed, selected portions of the telemetry data could be transferred to analysts over data lines. In anticipation of this situation, the investigator could be provided with software utilities for extracting and transmitting portions of the stored telemetry data.

6.3.3 Acquisition and Processing of all Downlink Data

Another functional allocation would assign the experimenter all acquisition and processing responsibilities. This would mean that the success or failure of the mission would be under the complete control of the investigator and his staff.

Ground equipment to perform these functions would necessarily be much more complex than in the previous example. The cost of data acquisition systems would be from $2 million to $5 million, the range primarily due to the uncertainty of using existing ground station resources [Ref. 10]. The cost of data processing systems is even more uncertain, but if the same system could be used for instrument development, launch support, and mission operations, this approach might be quite cost effective.

It seems likely that NASA will retain an interest in the performance of the spacecraft bus, and that the investigator will be required to furnish engineering telemetry data to NASA engineers.

During the Small Payloads workshop in February, 1987, several academic participants expressed a need for regular space science operations with short turnaround times from experiment conception to science data collection. The participants indicated that sensor data is needed for the advancement of science, and that space science activities are needed to allow the development of the next generation of space scientists. This functional allocation would clearly provide an investigator with an exceptional opportunity to produce valuable science insights, and it would also allow substantial graduate student involvement.

The investigator's team would probably have less mission management and operations experience than NASA's professional staff, so this approach implies an increased risk of mission degradation or failure as a result of errors. These risks could be greatly reduced by furnishing a small number of mission management and operations professionals to the investigator to train his team and to oversee their initial efforts. Because the potential science benefits are substantial, this approach bears further examination.

The coverage analysis of Section 3.3.2 suggests an opportunity to adopt a unified approach to EES communications. Since a ground station located at the equator provides coverage for all classes of low orbits, it appears likely that such a station could satisfy the majority of EES requirements as they are now understood.

Such a station could be provided by retaining the Ascension Island station. The station might require substantial renovation, as overhauls and upgrades have been omitted because of the planned closure. This need would drive costs upward. Further, the existing Ascension Island equipment is designed for substantial human involvement in operations.

If communication with an EES is performed at an equatorial location, it will be necessary to provide a link to related data processing facilities at GSFC. It may be possible to use the TDRSS facilities in an unconventional way for this purpose. The TDRSS C-Band antenna will be pointed at Europe and would be unable to link to an equatorial location. The S-Band antenna, however, might be used to echo EES data from a ground station. This approach appears to be technically feasible, but it might require a policy determination.

This approach suggests the possibility of extending the capabilities of the SN by using ground facilities. Figure 6.3-1 shows the end-to-end data flow that could be provided. Communication between NASA data processing facilities and the spacecraft could take place in real time, thus benefiting telemetry and command operations and permitting a form of telescience. Bulk science data could also be accumulated at the ground station and spooled through the TDRSS MA or SA systems when available. Similar joint use of space and ground systems is made when the Merritt Island Relay systems are used, providing a precedent for this approach

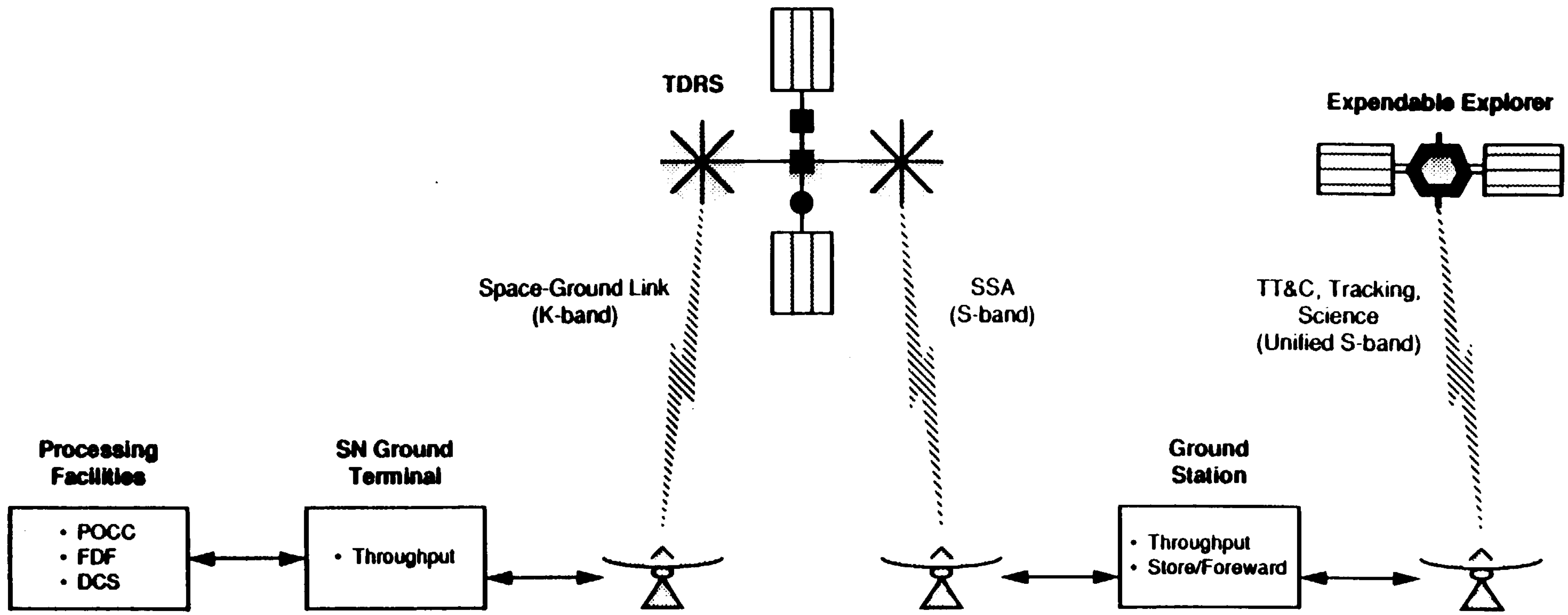


Figure 6.3-1. Use of Ground Facilities to Extend the Space Network

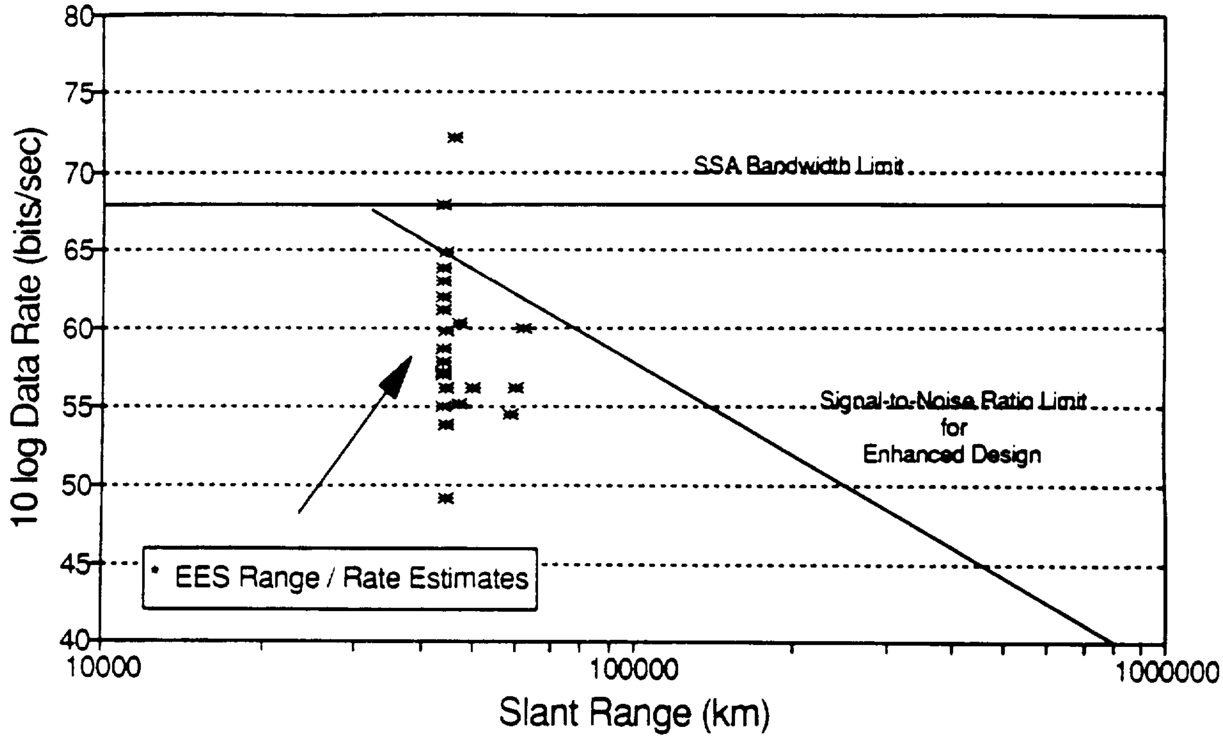
SECTION 7 - CONCLUSIONS

The design choices for the EES space segment communications and data handling subsystems heavily depend on the the capabilities of available space-to-ground communications systems, the types of orbits, and the characteristics of candidate instrument payloads. The following figures summarize the results of communications analysis for various classes of orbits and the selected instrument payloads, based on the characteristics of baseline and enhanced performance spacecraft designs.

Figures 7 - 1 through 7 - 3 contain graphs of data rate (as logarithm of bps) versus slant range (in km). The SSA and ground equipment bandwidth limits and the signal to noise ratio limits for the baseline (Figures 7-2 and 7-3) or enhanced versions (Figure 7-1) of the EES communications design [Ref. 2] provide the upper boundaries of the EES design. Plotted on these are the transmission data rates (as defined in Appendix D) required to support the individual strawman experiments at the maximum slant range to a TDRS or ground station (as defined in Appendix B). Feasibility of EES support for a specific strawman payload is shown when the plot of transmission data rate vs maximum slant range falls below the boundaries. Three graphs were developed to demonstrate the conclusions for the following cases: a) LEO via TDRSS, b) LEO via Wallops, and c) high Earth orbit (HEO) via Wallops. For this analysis a LEO has been defined as any orbit where the spacecraft is at an altitude less than 12,000 km for the majority of the time. The HEO has been defined as any orbit where the spacecraft is at an altitude greater than 12,000 km for the majority of the time.

Figure 7 - 1 shows the rate requirements versus rate limits for LEO spacecraft via TDRSS. The solid horizontal line shows the SSA data rate limit of 6 Mbps. The signal to noise ratio limit represents the enhanced EES communications design of the EES Study Team [Ref. 2]. Range/rate estimates for the strawman experiments in LEO are plotted as *. All but three of the strawman experiments fall below the SSA bandwidth limit and enhanced design signal to noise line. This indicates that the enhanced design could support all but three of the LEO strawman experiments. One of these three experiments, HEASI, falls below the SSA bandwidth limit but slightly above the signal to noise ratio limit for the enhanced design. Increasing the contact time could lower the required data rate enough to bring it within the limits of the enhanced design. The two remaining experiments can not be supported by either of the EES designs. The required data rate for these two experiments, Microphysics Explorer and Astro./Atmos. Spectroscopic Explorer, must be lowered before the EES can support them.

Figure 7 - 1. Rate Requirements versus Rate Limits for LEO Spacecraft via TDRSS



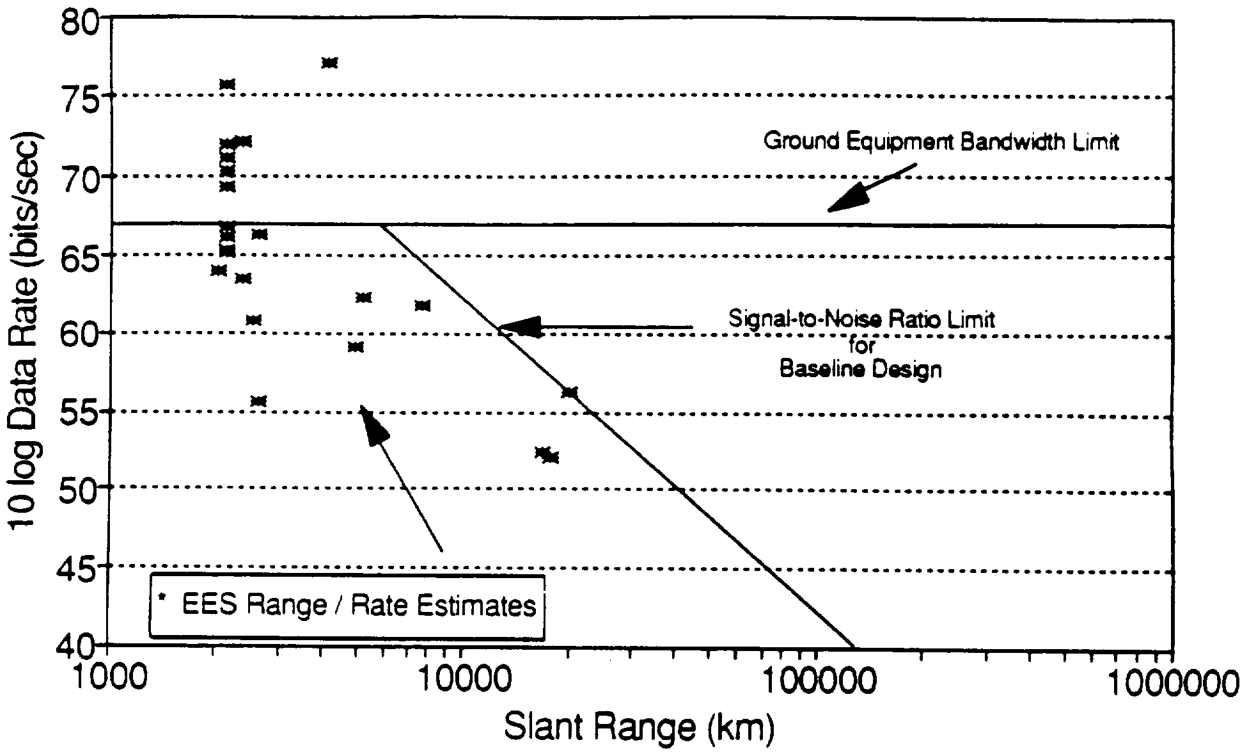
EES Payload	Max Range (km)	10 Log Data Rate bits/sec	EES Payload	Max Range (km)	10 Log Data Rate bits/sec
-------	----	--------	-------	----	--------
Microphysics Exp	46225	72.2	EXCAM	46225	57.9
Astro/Atmos	44053	67.9	SOFE	44053	57.1
HEASI	44335	64.9	LYMAN	44335	56.9
LUX	44053	63.9	ARTBE	44053	56.1
HECRE	44053	63.1	EMAO	44053	56.1
SHAPE	44053	62.2	HXRE	44053	56.1
SpEx	44053	61.2	AEROS	44053	55.2
SAMEX	47288	60.4	NAE	47288	54.9
Multiprobe Exp	62114	60.1	AIM	62114	54.6
HXSIE	44593	59.9	MELTER	44593	53.9
Asteroseismology	44053	58.7	NIREX	44053	49.2

Figure 7 - 2 shows the rate requirements versus rate limits for LEO spacecraft via Wallops. The solid horizontal line shows the Wallops data rate limit of 5 Mbps. The signal to noise ratio limit represents the baseline performance EES communications design [Ref. 10]. Range/rate estimates for the strawman experiments in LEO are plotted as $*$. Seven of the strawman experiments lie above the Wallops bandwidth limit because of the short contact time between a LEO and Wallops as discussed in section 3.3.3. Figure 7 - 1 shows that five of these seven experiments could be supported via TDRSS. The fifteen remaining strawman experiments could be supported by the baseline configuration via Wallops, but with some reservations as follows.

- Wallops presently provides throughput operations in support of COBE at 655 kbps and is capable of supporting rates up to 1.5 Mbps with only minor modifications. For rates above 1.5 Mbps (61.7 on the 10 log Data Rate Scale), upgrades will be required for Wallops communications and data handling equipment. For rates above 5 Mbps (67 on the 10 log Data Rate Scale), upgrades will also be required for Wallops RF equipment.
- AIM, ARTBE, and Multiprobe Explorer Mission are elliptical polar orbits and therefore it is recommended that support from the DSN at Canberra Australia be arranged in addition to Wallops support, as discussed in section 3.3.2, for these and similar type of missions.
- AEROS and EMAO have elliptical polar orbits that will decay to 600 km and 150 km orbits respectively after one year. The AEROS data rate can be supported by Wallops at 600 km, but the EMAO data rate cannot be supported at 150 km. Therefore it is recommended that TDRSS support be considered for missions similar to EMAO.

One more recommendation for the enhanced design for LEOs comes from discussion of Table 5.2.2-1 in section 5.2.2. It is recommended that a higher power transmitter with a five watt transmitter backup be used in the LEOs with orbits at 12,000 km and playback rates of 1250 kbps. This would allow more room for failure of a component, since both transmitter and antenna would have to fail for the link margin to be negative during contingency playback direct to ground.

Figure 7 - 2. Rate Requirements versus Rate Limits for LEO Spacecraft via Wallops



EES Payload	Max Range (km)	10 Log Data Rate bits/sec	EES Payload	Max Range (km)	10 Log Data Rate bits/sec
Microphysics E	4157	77.0	LYMAN	2136	65.1
Astro/Atmos	2136	75.7	NAE	2003	64.0
HEASI	2386	72.2	HXRE	2386	63.4
LUX	2136	72.1	SAMEX	5187	62.3
HECRE	2136	71.3	EMAO	7703	61.8
SHAPE	2136	70.4	MELTER	2528	60.7
SpEx	2136	69.4	AEROS	4959	59.1
Asteroseismolo	2136	66.9	Multiprob	19908	56.1
HXSIE	2620	66.4	NIREX	2620	55.6
EXCAM	2136	66.1	AIM	16741	52.4
SOFE	2136	65.3	ARTBE	17803	52.1

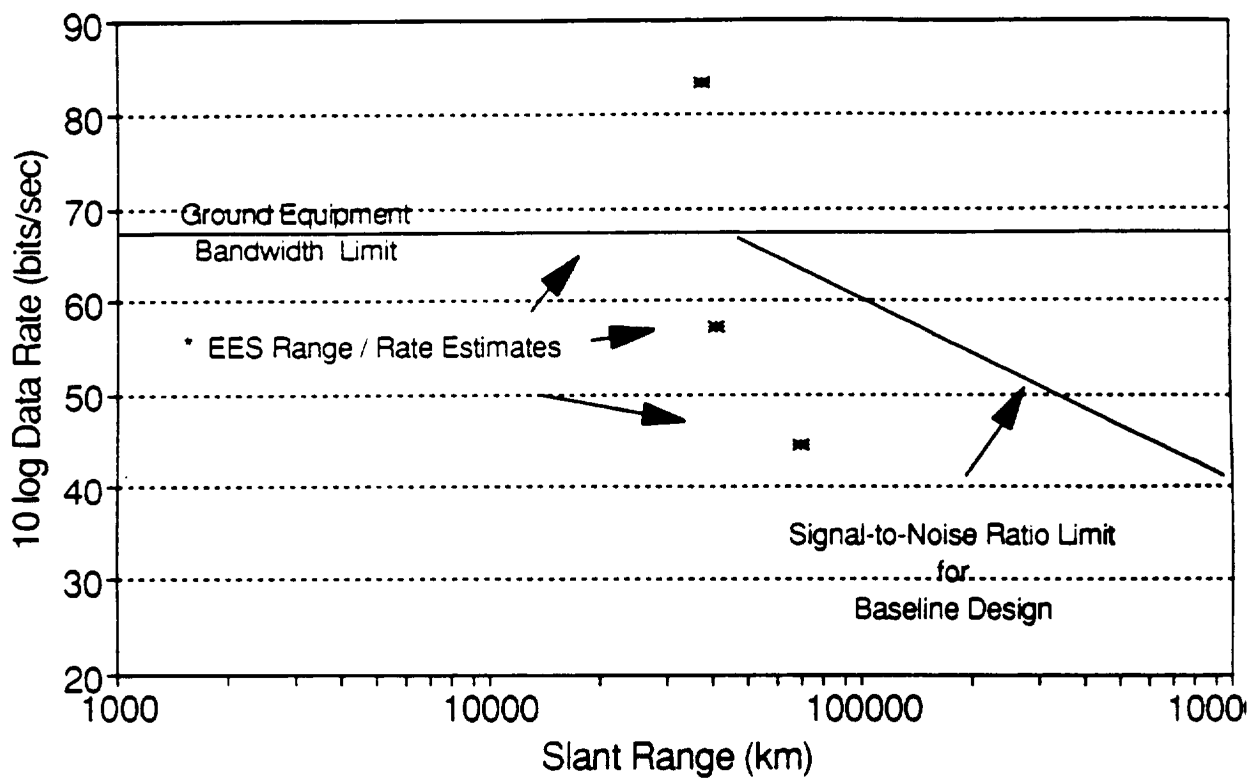
Figure 7 - 3 shows the rate requirements versus rate limits for HEO spacecraft via Wallops. The solid horizontal line shows the Wallops data rate limit of 5 Mbps. The signal to noise ratio limit represents the baselined EES communications design [Ref. 10] for GEO orbits. Strawman experiments in HEO are plotted as *. Of the three strawman experiments two could be supported via Wallops. QUASAT has a data rate so high that it would require K-Band support which is beyond the EES budget. Also, as noted in section 5.2.3, some HEO missions like SYNOP will need to operate in real-time and have the ability to point anywhere in the celestial sphere. The baseline and enhanced performance GEO EES design will not adequately support this type of operation because of antenna pointing constraints. It is recommended that the baseline design contain two shaped omni antennas and that the enhanced design contain the options of gimballed or fixed 19 dB antennas.

EES missions will be flown during the last years of TDRS operations and the initial years of ATDRS operations. EES missions active during the latter period could make use of service enhancements offered by ATDRSS, including the following:

- The SMA service will be enhanced by increasing forward link power 3 dB and increasing return link sensitivity 9 dB, permitting use of higher SMA data rates for noise-limited links.
- All SA services will be enhanced by increasing the SA antenna field of view, permitting support of user spacecraft at higher altitudes, including geocentric altitude.

Since three of the strawman payload set wish to operate at altitudes outside the TDRSS field of view but within the ATDRSS field of view, an ATDRSS scenario was examined for this class of missions. The strawman payloads all projected large data volumes, implying long SSA contact times. Substantial commitments of SSA services are typically reserved for high priority projects and may or may not be made available to the EES Program. In addition, an ATDRSS scenario is at a disadvantage compared to a ground scenario, since a ground antenna typically has a higher gain and may be closer to the user spacecraft. These considerations suggested that high altitude EES missions should plan to communicate directly with the ground, rather than through ATDRSS.

Figure 7 - 3. Rate Requirements versus Rate Limits for HEO Spacecraft via Wallops



EES Payload	Max Range (km)	10 log Data Rate bits/sec
--------	-----	--------
QUASAT	38532	83.4
SYNOP	41395	57.2
IMAGE	69586	44.5

REFERENCES

1 The Strawman experiments used for this study were selected from Scientific Evaluations of Proposals received in Response to EXPLORER CONCEPT STUDY PROGRAM NOTICE of March 14, 1986.

2 MDAC EES Study Team Status Reports.

3 SPACE NETWORK (SN) USER'S GUIDE, Revision 6, September 1988.

4 Advance TDRSS, Space Network Transition in the ATDRSS Era, April 1990.

5 ATDRSS Overview Presentation, Bill Guion, Chief, Space Network Project Office.

6 Communication with James Cooley, Code 554.0.

7 Commercial Delta II Payload Planners Guide, MDC H3224B, Dec 1989.

8 Data in the form of computer printouts and SEAS TEAM - QUICK NOTEs numbers QN 90/22 and QN 90/27 provided by NASA Code 554.0 in support of this study.

9 Communication with Robert Ciesielski, Code 530.2.

10 Cost data provided by Steve Talabac, CTA Project Engineer, and Charles Vermillion, Code 670. Charles Vermillion has installed data acquisition and processing equipment at locations around the world for more than 20 years.

11 Request for Waiver to Permit the Cosmic Background Explorer (COBE) to Use a Ground Receiving Station to Collect Science Data, memo from GSFC Director to NASA Headquarters, November 13, 1981.

12 Satellite Communications, Robert M. Gagliardi, 1984.

APPENDIX A: CONTACT TIME

APPENDIX A - CONTACT TIME

Code 554.0 was provided with orbit parameters for 16 of the strawman instruments so that they could produce accurate view periods with ground stations and TDRSS. These were used to provide accurate contact time values for the link analysis. These 16 were used out of the 25 strawman instruments because their orbit parameters represented the entire group. Two of the experiments, ACE and LUSTER, have since been dropped from the strawman since their weight and desired orbit altitude were not feasible for a Delta launch. The contact times produced by Code 554.0 are given in the following Tables. For all the tables in this appendix, view periods with a ground station that were less than five minutes were omitted from the tables as not being useful for data playback. Likewise, view periods that were split by the horizon mask were omitted if none of the parts was longer than five minutes. If a part of the view period was longer than five minutes than that part was used as the view period, not the sum of the parts split by the horizon mask.

The tables are arranged into groups as follows:

- Tables A-1 through A-12 provide the results of six strawman instruments with elliptical orbits. Four of the instrument orbits (AEROS,ARTBE, Microphysics Explorer, and Multiprobe Explorer) were studied to see their view times with TDRS1, TDRS2, Wallops (WPSA), Goldstone (DS16), Fairbanks Alaska (ULAE), Canberra Australia (DS46), and Madrid Spain (DS66). A set of view times was derived for the cases when the spacecraft apogee occured over the Indian Ocean and when perigee occured over the Indian Ocean. These two cases should have provided the minimum view times with a TDRS. Two of the instrument orbits (AIM and EMAO) were studied to see their view times with TDRS1, TDRS2, and Wallops when the spacecraft apogee occured over Wallops and when perigee occured over Wallops. These two cases should have provided the minimum view times with Wallops which they did during one of their view periods of the day. However, 12 hours later perigee was no longer over WPSA and the view periods were longer.
- Tables A-13 through A-15 provide the results of three strawman instruments with 28.5 degree LEOs at 500 km, 600 km, and 700 km.

- Table A-16 provides the results for a strawman instrument that requests a 500 km circular LEO at a 57 degree inclination. Only the view times with TDRS1, TDRS2, and Wallops were studied.
- Tables A-17 and A-18 provide the results of two strawman instruments with polar LEOs at 2150 km and 500 km. The average number of contacts per day was added for convenience. Note that the orbit inclination is dependent on orbit altitude.
- Tables A-19 through A-23 provide the results of five strawman instruments with elliptical polar orbits, the 'e' stands for eccentricity of the orbit. The average number of contacts per day was added for convenience.

Table A-1. AEROS, Apogee Over the Indian Ocean

Event #	Satellite view time (in minutes) at the given stations						
	TDRS1	TDRS2	Wallops WPSA	Goldstone DS 16	Alaska ULAE	Canberra DS 46	Madrid DS 66
1	90.00	98.50	21.00	22.15	12.84	19.27	9.47
2	258.00	79.00	5.00	23.90	16.44	25.22	7.05
3	70.00	75.00	12.47	8.98	15.27	10.00	20.35
4	67.00	75.00	19.12	11.05	16.34	13.05	20.48
5	74.00	79.00	24.46	10.49	11.19	20.72	9.92
6	255.00	258.00	15.44	23.10	8.80	25.04	20.86
7	82.00	78.00	5.92	23.43	10.73	8.11	19.57
8	76.00	69.00	12.34	7.84	10.79	12.49	
9	76.00	68.00	20.09	11.48	8.81		
10	78.00	82.00	24.60	5.48	13.41		
11	357.00	263.00		6.62	16.42		
12	69.00	79.00			15.60		
13	67.00	76.00			15.94		
14	256.00	76.00			10.33		
15	80.00	80.00			9.16		
16	75.00	256.00			10.52		
17	75.00	75.00			10.99		
18	72.50	68.00			8.21		
19		69.00			6.85		
20		238.50					
Average	120.97	112.10	16.04	14.05	12.03	16.74	15.39

Period = 111.6 Minutes

Inclination = 90 degrees

Above table represent events during a two day period.

Table A-2. AEROS, Perigee Over the Indian Ocean

Event #	Satellite view time (in minutes) at the given stations						
	TDRS1	TDRS2	Wallops WPSA	Goldstone DS 16	Alaska ULAE	Canberra DS 46	Madrid DS 66
1	320.50	151.5	9.14	12.10	9.22	11.20	17.47
2	78.00	71.00	23.45	19.50	10.40	10.08	21.31
3	75.00	67.00	23.43	24.38	10.92	23.59	12.95
4	76.00	71.00	10.39	18.85	8.09	21.83	10.24
5	81.00	255.00	11.30	12.21	12.48	6.93	18.82
6	255.00	84.00	10.84	21.13	15.64	12.00	20.99
7	74.00	77.00	24.01	24.31	14.97	5.00	10.19
8	68.00	75.00	22.68	9.00	16.58	7.33	
9	69.00	77.00	11.39		11.83	24.48	
10	260.00	87.00			9.59	22.20	
11	92.00	256.00			10.14		
12	78.00	71.00			10.84		
13	75.00	68.00			7.49		
14	77.00	72.00			5.09		
15	83.00	254.00			12.95		
16	255.00	82.00			16.09		
17	72.00	76.00			15.21		
18	67.00	. 75.00			16.38		
19	71.00	77.00			10.89		
20	17.50	186.50					
Average	112.20	111.65	16.29	17.69	11.83	14.46	14.00

Period = 111.6 minutes — Inclination = 90 degrees

Above table represents events during a 2 day period.

Table A-3 . AIM, Perigee over Wallops

Event #	Satellite view time (in minutes) at the given stations.		
	TDRS1	TDRS2	Wallops WPSA
1	573.00	493.00	6.86
2	203.00	176.00	59.25
3	491.00	401.00	83.47
4	577.00	203.00	7.00
5	202.00	217.00	5.37
6	220.00	282.00	14.73
7	275.00	177.00	86.40
8		376.00	20.64
9		203.00	
10			
11			
Average	363.00	280.89	35.47

Orbit altitude = 300 X 12000 km Inclination = 90 degrees

Above table represents events during a 2 day period.

Table A-4 . AIM, Apogee over Wallops

Event #	Satellite view time (in minutes) at the given stations.		
	TDRS1	TDRS2	Wallops WPSA
1	116.00	362.00	95.22
2	211.00	205.00	141.62
3	489.00	206.00	130.18
4	364.00	486.00	41.35
5	204.00	360.00	42.44
6	208.00	208.00	30.79
7	487.00	204.00	95.71
8	361.00	488.00	139.67
9		203.00	140.76
10			44.92
11			43.48
12			26.09
13			81.00
14			31.00
Average	305.00	302.44	77.45

Orbit altitude = 300 X 12000 km Inclination = 90 degrees

Above table represents events during a 2 day period.

Table A-5. ARTBE, Apogee Over the Indian Ocean

Event #	Satellite view time (in minutes) at the given stations						
	TDRS1	TDRS2	Wallops WPSA	Goldstone DS 16	Alaska ULAE	Canberra DS 46	Madrid DS 66
1	499.50	344.50	58.00	22.00	35.74	64.55	50.14
2	228.00	581.00	131.96	68.95	38.85	22.61	127.63
3	585.00	229.00	135.55	141.53	66.66	135.37	106.25
4	360.00	584.00	8.50	50.50	93.09	131.56	5.11
5	233.00	358.00	22.04	19.58	97.74	41.39	16.59
6	237.00	235.00	94.95	14.08	57.00	9.17	97.59
7	355.00	236.00	142.47	18.47	30.71	22.12	133.06
8			25.00	118.55	46.96	145.47	19.06
9			21.24	141.69	78.28		
10					85.13		
11					86.96		
Average	356.79	366.79	71.08	66.15	65.19	71.53	69.43

Period = 4.28 hours   Inclination = 90 degrees

Above table represent events during a 2 day period.

Table A-6. ARTBE, Perigee Over the Indian Ocean

Event #	Satellite view time (in minutes) at the given stations						
	TDRS1	TDRS2	Wallops WPSA	Goldstone DS 16	Alaska ULAE	Canberra DS 46	Madrid DS 66
1	499.50	344.50	58.05	22.00	35.74	64.55	50.14
2	228.00	581.00	131.96	68.95	38.85	22.61	127.63
3	585.00	229.00	135.55	141.53	66.66	135.37	106.25
4	360.00	584.00	8.50	50.50	93.09	131.56	5.11
5	233.00	358.00	22.04	19.58	97.74	41.39	16.59
6	237.00	235.00	94.95	14.08	57.00	9.17	97.59
7	355.00	236.00	142.47	18.47	30.71	22.12	133.06
8			25.00	118.55	46.96	145.47	19.06
9			21.24	141.69	78.28		
10					85.13		
11					86.69		
Average	356.79	366.79	71.08	66.15	65.17	71.53	69.43

Period = 4.28 hours   Inclination = 90 degrees

Above table represent events during a 2 day period.

Table A-7 . EMAO, Perigee over Wallops

Event #	Satellite view time (in minutes) at the given stations		
	TDRS1	TDRS2	Wallops WPSA
1	85.00	117.00	10.00
2	203.00	278.00	30.88
3	104.00	80.00	27.04
4	96.00	85.00	30.24
5	94.00	202.00	28.64
6	98.00	105.00	
7	113.00	97.00	
8	276.00	95.00	
9	80.00	98.00	
10	83.00	112.00	
11	202.00	276.00	
12	109.00	79.00	
13	96.00	83.00	
14	95.00	203.00	
15	110.00	109.00	
16	95.00	97.00	
17	275.00	97.00	
18	81.00		
Average	127.50	130.18	25.36

Orbit altitude = 150 X 4000 km   Inclination = 90 degrees

Above table represents events during a 2 day period.

Table A-8 . EMAO, Apogee over Wallops

Event #	Satellite view time (in minutes) at the given stations		
	TDRS1	TDRS2	Wallops WPSA
1	99.00	200.00	35.48
2	116.00	104.00	46.63
3	276.00	95.00	42.42
4	79.00	95.00	9.62
5	84.00	98.00	19.44
6	201.00	115.00	15.35
7	106.00	276.00	11.48
8	96.00	79.00	38.22
9	94.00	84.00	46.00
10	98.00	202.00	36.00
11	111.00	107.00	44.08
12	275.00	97.00	10.72
13	80.00	95.00	6.28
14	82.00	97.00	18.95
15	312.00	110.00	16.82
16	97.00	275.00	36.12
17	87.00	80.00	
18		82.00	
Average	134.88	127.28	27.10

Orbit altitude = 150 X 4000 km   Inclination = 90 degrees

Above table represents events during a 2 day period.

Table A-9. Microphysics Explorer, Apogee Over the Indian Ocean

Event #	Satellite view time (in minutes) at the given stations						
	TDRS1	TDRS2	Wallops WPSA	Goldstone DS 16	Alaska ULAE	Canberra DS 46	Madrid DS 66
1	74.00	76.50	9.95	19.83	12.28	9.76	8.57
2	83.00	71.00	10.33	9.68	8.52	18.80	6.42
3	77.00	69.00	6.76	10.32	7.69	17.61	10.02
4	67.00	69.00	11.88	9.04	12.82	12.03	17.08
5	63.00	71.00	15.78	7.59	13.33	7.56	15.26
6	65.00	75.00	18.88	12.47	11.14	8.37	8.14
7	73.00	83.00	15.96	18.20	8.29	9.33	6.70
8	84.00	77.00	10.54	19.86	8.06	15.29	10.39
9	77.00	66.00	8.55	8.15	12.91	18.83	17.21
10	72.00	63.00	7.67	10.47	13.31	13.38	14.37
11	69.00	65.00	12.64	9.00		11.17	
12	69.00	73.00	16.21	7.92		7.56	
13	71.00	83.00	19.07	13.14		8.18	
14	75.00	77.00	15.64	18.57		8.96	
15	83.00	71.00					
16	75.00	69.00					
17	65.00	69.00					
18	63.00	76.00					
19	66.00	83.00					
20	74.00	75.00					
21	83.00	66.00					
22	76.00	63.00					
23	71.00	65.00					
24	69.00	75.00					
25	69.00	84.00					
Average	72.52	72.58	12.85	12.45	10.84	11.92	11.42

Period = 1.73 hours

Inclination = 57 degrees

Above table represents events during a 2 day period.

Table A-10. Microphysics Explorer, Perigee Over the Indian Ocean

Event #	Satellite view time (in minutes) at the given stations						
	TDRS1	TDRS2	Wallops WPSA	Goldstone DS 16	Alaska ULAE	Canberra DS 46	Madrid DS 66
1	83.00	78.00	18.99	6.70	9.08	10.86	8.82
2	72.00	67.00	20.70	19.81	6.47	9.13	17.80
3	77.00	63.00	13.27	19.05	14.13	8.61	14.51
4	70.00	65.00	7.75	13.38	13.19	12.72	8.85
5	69.00	72.00	8.92	7.78	10.16	18.22	5.92
6	70.00	84.00	9.29	8.67	6.01	18.87	7.28
7	75.00	78.00	8.05	10.27	5.69	10.49	10.24
8	83.00	71.00	19.67	8.06	9.23	8.49	17.90
9	76.00	69.00	20.33	20.09	14.28	9.09	12.58
10	66.00	69.00	13.30	18.60	12.93	12.72	5.05
11	63.00	71.00	7.17	12.91	7.94	18.56	7.77
12	65.00	75.00	9.19	7.50		18.70	
13	74.00	83.00	9.29	8.87			
14	84.00	76.00					
15	76.00	66.00					
16	71.00	63.00					
17	69.00	65.00					
18	69.00	74.00					
19	71.00	83.00					
20	76.00	77.00					
21	84.00	71.00					
22	74.00	69.00					
23	65.00	69.00					
24	63.00	71.00					
25	66.00	76.00					
Average	72.44	72.20	12.76	12.44	9.92	13.04	10.61

Period = 1.73 hours

Inclination = 57 degrees

Above table represents events during a 2 day period.

Table A-11. Multiprobe Explorer, Apogee Over the Indian Ocean

Event #	Satellite view time (in minutes) at the given stations						
	TDRS1	TDRS2	Wallops WPSA	Goldstone DS 16	Alaska ULAE	Canberra DS 46	Madrid DS 66
1	630.00	265.50	155.10	167.56	99.49	19.42	28.96
2	388.00	252.00	49.05	126.02	104.00	134.27	6.34
3	254.00	646.00	15.57	15.89	76.65	168.57	94.00
4	629.00	423.00	136.43	165.63	39.25	14.04	152.37
5	371.00	252.00	161.90	139.98	34.96	118.56	53.59
6	257.00	629.00	66.25	6.57	92.02	170.11	14.49
7			18.08	11.89	98.41	18.23	155.37
8			59.47	64.02	84.25		63.29
9			66.20		46.51		
10					30.29		
11					80.06		
Average	421.50	411.25	80.89	87.20	71.44	91.89	71.05

Period = 4.64 hours Inclination = 90 degrees

Above table represents events during a 2 day period.

Table A-12. Multiprobe Explorer, Perigee Over the Indian Ocean

Event #	Satellite view time (in minutes) at the given stations						
	TDRS1	TDRS2	Wallops WPSA	Goldstone DS 16	Alaska ULAE	Canberra DS 46	Madrid DS 66
1	543.50	367.00	69.63	16.81	32.36	77.72	56.71
2	253.00	367.00	160.79	119.49	40.07	18.96	152.05
3	391.00	261.00	116.53	167.68	80.80	170.53	57.00
4	631.00	256.00	15.91	17.91	100.36	118.15	13.20
5	252.00	374.00	60.36	85.72	101.75	17.54	44.83
6	645.50	628.00	153.38	166.81	37.55	168.49	146.50
7		253.00	149.28		36.80	66.46	131.36
8			11.07		73.85		
9					105.42		
10					108.96		
Average	452.67	358.00	92.12	95.74	71.79	91.12	85.95

Period = 4.64 hours   Inclination = 90 degrees

Above table represents events during a 2 day period.

Table A-13. SpEx

Event #	Satellite View Time (in minutes) at the given stations				
	Wallops WPSA	Goldstone DS 16	Alaska ULAE	Canberra DS 46	Madrid DS 66
1	8.20	6.12		5.31	7.17
2	8.48	9.22		8.06	6.39
3	5.80	9.67		8.32	
4	8.65	9.08		7.77	
5		5.59			
Average	7.78	7.94	0.00	7.37	6.39

Period = 1.58 hours Inclination = 28.5 degı Orbit = 500 km

Above table represents events during a 24 hour period.

Table A-14. HEASI

Event #	Satellite view time (in minutes) at the given stations				
	Wallops WPSA	Goldstone DS 16	Alaska ULAE	Canberra DS 46	Madrid DS 66
1	10.60	8.15		6.91	8.05
2	9.89	10.57		6.90	8.65
3	6.50	11.22		9.77	7.36
4	7.69	9.94		9.50	
5	10.43	7.13		8.51	
Average	9.02	9.40		8.32	8.02

Period = 1.61 hours Inclination = 28.5 degı Orbit = 600 km

Above table represents events during a 24 hour period.

Table A-15. HXSIE

Event #	Satellite view time (in minutes) at the given stations				
	Wallops WPSA	Goldstone DS 16	Alaska ULAE	Canberra DS 46	Madrid DS 66
1	11.81	9.60		7.98	9.62
2	11.08	11.68		8.18	9.71
3	7.32	12.47		10.77	7.81
4	10.49	10.94		10.30	
5	11.21	8.22			
6		5.65			
Average	10.38	9.76		9.31	9.05

Period = 1.65 hours Inclination = 28.5 degı Orbit = 700 km

Above table represents events during a 24 hour period.

Table A-16. Asteroseismology Explorer

Satellite view time (in minutes) at the given stations.			
Event #	TDRS1	TDRS2	Wallops WPSA
1	62.00	68.00	10.90
2	68.00	62.00	6.75
3	65.00	57.00	7.20
4	59.00	56.00	9.16
5	57.00	57.00	5.84
6	56.00	60.00	10.43
7	58.00	65.00	9.32
8	62.00	68.00	6.54
9	68.00	62.00	8.64
10	65.00	58.00	8.29
11	60.00	57.00	9.70
12	57.00	57.00	9.97
13	57.00	59.00	5.22
14	58.00	64.00	8.89
15	60.00	68.00	9.52
16	67.00	62.00	5.77
17	66.00	58.00	10.77
18	60.00	57.00	6.53
19	57.00	56.00	6.97
20	56.00	59.00	9.75
21	57.00	64.00	
22	60.00	68.00	
23	66.00	63.00	
24	67.00	58.00	
25	61.00	56.00	
26	57.00	57.00	
27	56.00	59.00	
28	57.00	53.00	
29	60.00	63.00	
30	66.00	63.00	
31	67.00	59.00	
32	61.00	57.00	
33	57.00	57.00	
34	57.00	59.00	
35	57.00	63.00	
36	60.00	68.00	
37	65.00	64.00	
38	68.00	59.00	
39	61.00	57.00	
40	58.00	56.00	
41	57.00	58.00	
42	56.00	63.00	
43	59.00	68.00	
44	65.00	65.00	
45	68.00	59.00	
46	62.00	57.00	
47	58.00	56.00	
48	56.00	58.00	
49	57.00	61.00	
50	59.00	67.00	
51	64.00	66.00	
52	68.00	59.00	
53	63.00	57.00	
54	58.00	57.00	
55	56.00	58.00	
56	57.00	61.00	
Average	60.70	60.41	8.31
Average no. Views per Day	14.00	14.00	5.00

Period=1.58 hours Inclination=57 degrees.

Above table represents events during a 4 day period.

Table A-17. SAMEX

Event #	Satellite View Time (in minutes) at the given stations				
	Wallops WPSA	Goldstone DS 16	Alaska ULAE	Canberra DS 46	Madrid DS 66
1	26.97	26.35	24.71	25.23	22.39
2	25.20	23.86	20.72	26.89	21.54
3	16.50	26.58	17.80	17.41	14.08
4	17.43	16.67	9.91	12.53	22.76
5	25.04	10.86	19.99	22.03	20.71
6	24.83	22.74	21.58	26.52	19.01
7	17.61	14.40	25.26	26.25	15.72
8	25.96	24.23	25.09	27.22	15.72
9	23.24	26.17	25.24	25.77	23.45
10	26.85	25.64	24.92	15.85	19.59
11	23.20	25.71	25.18	14.65	14.36
12		16.76	25.15	24.06	22.85
13			24.28		
14			20.66		
15			14.95		
16			13.39		
17			20.28		
18			23.43		
Average	22.98	21.66	21.25	22.03	19.35
Ave # Contacts Per Day	6.50	6.00	9.00	6.50	6.50

Period = 2.18 hours Inclination = 106 degress Altitude = 2150 km

Above table represents events during a 2 day period.

Table A-18. Astro./Atmos. Spectroscopic Explorer

Event #	Satellite View Time (in minutes) at the given stations				
	Wallops WPSA	Goldstone DS 16	Alaska ULAE	Canberra DS 46	Madrid DS 66
1	9.66	8.95	5.20	7.44	5.78
2	8.74	9.09	6.80	10.13	7.54
3	8.95	9.44	6.79	8.60	7.84
4	9.64	7.94	5.67	8.37	7.68
5	9.43	8.70	6.39	9.79	
6		9.59	6.55		
7			6.45		
8			6.64		
9			5.74		
10			6.35		
11			6.96		
12			6.13		
Average	9.28	8.95	6.31	8.87	7.21
Ave # Contacts Per Day	2.50	3.00	6.00	2.50	2.50

Period = 1.58 hours Inclination = 97.5 degress Altitude = 500 km

Above table represents events during a 47 hour period.

Table A-19. Aeros

Event #	Satellite view time (in minutes) at the given stations				
	Wallops WPSA	Goldstone DS 16	Alaska ULAE	Canberra DS 46	Madrid DS 66
1	8.73	12.14	10.21	11.23	16.57
2	23.72	19.86	10.03	6.73	21.43
3	23.30	24.39	10.39	7.05	13.35
4	12.02	18.86	5.73	12.20	9.14
5	10.86	5.78	11.28	24.62	11.32
6	13.80	13.79	15.48	21.82	11.36
7	12.83	11.80	15.07	20.94	18.43
8	11.62	22.17	16.71	23.16	19.75
9	15.85	8.56	12.91	9.96	5.73
10	22.81	20.59	6.13	10.70	5.81
11	18.01	22.22	7.72	21.72	19.36
12	18.29	10.60	7.07	20.48	18.53
13	22.93	9.20	8.13	14.61	10.18
14	15.08	21.36	5.79	14.66	8.78
15	10.61	13.39	7.66	23.33	11.41
16	14.04	11.12	8.29	10.02	6.12
17	14.20	12.78	19.69	18.87	16.32
18	10.96	12.21	18.94	23.56	20.12
19	22.25	19.08	19.77	11.69	7.95
20	21.33	22.56	18.61	20.46	18.41
21	10.77	10.69	18.73	13.10	19.45
22	22.25	18.77	18.13	12.11	
23	21.48	22.58	19.73	11.77	
24		12.33	18.64		
25			19.76		
26			16.68		
27			17.69		
28			16.96		
29			18.11		
30			6.04		
32			7.60		
32			8.31		
33			8.09		
34			7.84		
35			6.03		
36			17.11		
37			17.63		
38			17.46		
39			19.20		
40			18.51		
41			20.02		
42			18.30		
43			18.44		
44			18.42		
45			19.18		
46			18.37		
47			19.92		
48			17.37		
Mean	16.42	15.70	14.25	15.86	13.79
Ave # Contacts Per Day	5.2	5.4	9.6	1.8	1.8

Period = 111.6 minutes e = 0.09 Inclination = 90 degrees

Above table represents events during a 4.8 day period.

Table A-20. ARTBE

Event #	Satellite view time (in minutes) at the given stations				
	Wallops WPSA	Goldstone DS16	Alaska ULAE	Canberra DS46	Madrid DS66
1	133.95	22.78	32.73	16.52	126.42
2	134.10	142.50	44.07	15.73	120.66
3	45.66	115.20	88.13	8.58	16.52
4	23.22	14.86	87.60	107.28	18.95
5	143.22	14.80	75.60	145.08	133.20
6	108.03	80.00	47.18	24.09	92.23
7	34.89	140.34	30.91	137.04	27.71
8	34.75	30.04	61.14	123.77	27.62
9	28.74	31.40	94.48	100.60	12.13
10	154.45	32.78	13.22	105.27	18.20
11	130.94	128.08	12.49	128.08	119.22
12	115.71	153.30	9.49	147.58	101.37
13	81.07	124.98	11.81	129.54	68.36
14	116.55	105.58	7.71	109.66	111.35
15	130.36	98.01	9.16	29.25	123.14
16	136.25	120.88	135.95	27.05	123.15
17	125.59	139.53	162.27	36.32	117.04
18	34.20	136.09	155.93	131.73	93.76
19	29.20	25.34	134.76	155.52	91.12
20	16.64	15.20	137.17	127.94	24.31
21	26.42	34.69	134.77	107.59	24.70
22	119.72	34.32	144.70	95.97	27.65
23	134.49	102.75	163.30	120.60	126.07
24	134.14	123.14	6.09	141.03	122.21
25	123.35	143.31	8.07	136.84	114.75
26	100.08	130.60	11.98	34.00	83.48
27	108.92	116.94	11.20	34.97	96.67
28	125.01	93.53	13.52	29.53	118.24
29	154.42	107.51	12.00		144.49
30		128.60	13.20		119.18
31			137.84		
32			133.20		
33			152.24		
34			161.47		
35			137.60		
36			137.67		
37			140.06		
38			135.99		
Average	96.00	89.57	79.12	89.54	84.80
Ave # Contacts Per Day	12.63	11.79	10.41	11.78	11.16

Period = 4.28 hours e = 0.45 Inclination = 90 degrees

Above table represents events during a 7.6 day period.

Table A-21. IMAGE

Event #	Satellite view time (in minutes) at the given stations				
	Wallops WPSA	Goldstone DS16	Alaska ULAE	Canberra DS46	Madrid DS66
1	889.00	1032.00	880.00	948.00	520.00
2	252.00	503.00	276.00	640.00	286.00
3	521.00	224.00	1225.00	421.00	353.00
4	612.00	1172.00		342.00	251.00
5					637.00
6					331.00
Average	568.50	732.75	793.67	587.75	396.33
Ave # Contacts Per Day	1.10	1.10	0.80	1.10	1.60

Period = 29.05 hours e = 0.47 Inclination = 90 degrees

Above table represents events during a 3.6 day period.

Table A-22. QUASAT

Event #	Satellite View Time (in minutes) at the given stations				
	Wallops WPSA	Goldstone DS 16	Alaska ULAE	Canberra DS 46	Madrid DS 66
1	662.70	633.45	399.77	300.43	373.64
2	194.88	317.21	227.57	213.36	651.88
3	147.29	413.42	443.35	802.74	283.79
4	284.62	756.58	180.37	263.58	255.77
5	448.12	337.73	333.66	151.61	505.05
6	755.14	397.85	602.96	111.69	735.71
7	178.08	705.99	447.34	773.29	310.99
8	546.04		102.53	430.77	582.17
9	794.46		288.61	421.12	605.47
10	221.43		258.14		
11			523.09		
12			313.74		
Average	423.28	508.89	343.43	385.40	478.27
Ave # Contacts Per Day	2.00	1.40	2.40	1.80	1.80

Period = 16.13 hours　　e = 0.22　　Inclination = 63 degrees

Above table represents events during a five day period.

Table A-23. Microphysics Explorer

Event #	Satellite view time (in minutes) at the given stations				
	Wallops WPSA	Goldstone DS 16	Alaska ULAE	Canberra DS 46	Madrid DS 66
1	7.72	10.48	8.10	8.16	17.23
2	12.76	8.96	12.92	8.90	14.26
3	16.32	7.98	13.30	17.27	7.84
4	19.04	13.18	9.82	20.47	7.69
5	15.60	18.60	7.95	13.01	14.52
6	11.01	19.62	8.49	10.07	17.27
7	9.01	6.19	13.04	7.68	10.38
8	8.17	10.46	13.24	8.31	7.41
9	13.48	8.54	9.31	8.69	7.57
10	17.25	8.53	7.54	16.86	7.29
11	19.21	12.86	8.35	18.94	8.05
12	10.74	19.11	13.60	5.79	5.56
13	5.56	19.19	19.18	18.74	5.51
14	9.35	5.49	19.99	17.76	16.70
15	6.05	5.63	13.97	17.02	5.82
16	11.03	10.36	18.63	16.87	17.40
17	7.60	10.56	11.02	18.31	17.18
18	5.69	5.23	9.57	18.86	15.83
19	9.67	5.85	13.91	5.83	15.03
20	19.13	20.29	19.55	7.92	17.38
21	17.09	17.59	19.91	7.82	16.29
22	18.73	17.82	18.41	7.20	7.41
23	18.23	16.84	13.66	7.17	
24	17.18	19.97	10.04	10.30	
25	21.11	16.65		8.53	
26	18.13	18.55		6.88	
27	18.93	20.17			
28	16.58	12.29			
29	18.74	17.80			
30	17.79	16.65			
31		19.95			
32		15.66			
Average	13.90	13.66	13.06	12.05	11.80
Ave # Contacts Per Day	2.82	2.78	2.65	2.45	2.40

Period = 1.73 hours e = 0.08 Inclination = 57 degrees

Above table reprents events during a 4 day 22 hours period.

APPENDIX B: MAXIMUM SLANT RANGE

TO:	Mr. J. Cooley and Mr. M. Saltzberg	DATE:	June 19, 1990
		PAGE:	1 of 2
FROM:	Dr. L. Roszman		
PREPARER:	Mr. V. Blaes		
SUBJECT:	Maximum and Minimum Slant Range to 13 Expandable Explorer Satellites from Five Ground Tracking Stations		

SEAS QUICK NOTE NO.: QN 90/22

TASK ASSIGNMENT NO.: 50-404

This Quick Note is in response to a request for the maximum and minimum ranges from 5 ground tracking stations to the Expandable Explorer satellite in 13 different mission orbits. The given Orbit parameters for the experiments are described in Table 1. The five tracking stations are: Canberra (DS46), Fairbanks (ULAE), Goldstone (DS16), Madrid (DS66), and Wallops Island (WPSA). Elevation masks for the tracking antennas are presented in Tables 2 through 6.

1. ABSOLUTE MINIMUM AND MAXIMUM SLANT RANGE FROM GROUND TRACKING STATIONS

The maximum possible slant range from the tracker to the satellite occurs when the satellite is at apogee, and apogee is above the equator. For this case the slant range, S, is given by:

$$S = -R * \sin(\acute{A}) + [(R_e + H_a)^2 - (R * \cos(\acute{A}))^2]^{1/2} \tag{1}$$

where,
- R = Earth radius at the tracker, plus tracker altitude
- R_e = Equatorial Earth radius
- $\acute{A}$ = tracker elevation mask angle
- H_a = satellite apogee altitude

The minimum possible slant range is equal to perigee altitude when perigee is directly above the tracker. The computed absolute minimum and maximum slant ranges for each satellite-tracker combination is presented in Tables 7 through 11.

2. ABSOLUTE MAXIMUM AND MINIMUM RANGE FROM TDRSS TRACKERS

Four of the elliptical orbits are required to be tracked by TDRSS trackers in addition to ground trackers. There are two geometric constraints on tracking from TDRSS. The perpendicular distance from TDRSS-to-target line of sight to the Earth must be neither greater than 12000 km, nor less than 100 km. The longest slant range from TDRSS to target for a given distance between the TDRSS line of sight to the target and the Earth occurs when the target is at apogee altitude. It is obtained from the following equation, where H is the perpendicular distance from the TDRSS to target line of sight, H_a is the apogee altitude, and $H_a > H$.

$$\text{Range} = [(6378.14 + H_a)^2 - (6378.14 + H)^2)]^{1/2} + [42241.1^2 - (6378.14 + H)^2]^{1/2} \tag{2}$$

The maximum slant range for a given apogee altitude is obtained when H is minimum, i.e., H = 100 km. Minimum slant range from TDRSS to the target satellite occurs when the apogee of the target's orbit is directly beneath TDRSS. The computed minimum and maximum ranges are shown in Table 12 for four target satellites.

3. COMPUTED SLANT RANGES USING THE ACQSCAN PROGRAM

The initial orbital elements for the 13 orbits were not specified. However, all launches except those for ACE, SPEX, HEASI and HXSIE are known to be from Vandenburg AFB. The rest will be from Cape Kennedy. The right ascension of the first ascending node was selected to make the ground track of the first orbit pass through the launch site geodetic coordinates. The satellite mass was known, but the reference area was not, hence, lifetime duration ephemerides were not computed. Instead, 5 combinations of right ascension of the ascending node and argument of perigee were employed to generate one to two days of tracking data using the ACQSCAN program, with drag turned off. Table 13 presents the combinations of right ascension and argument of perigee used for each run. It should be noted that it was necessary to run each case with two output options, since it is currently not possible to obtain both slant ranges and event durations in the same ACQSCAN run. Also, the slant range cannot be computed using ACQSCAN if the size of the range number is greater than five places to the left of the decimal because then the output format width provided for is exceeded. This occurred in two cases; for ACE and LUSTER. The runs show that slant ranges near the maximum possible value occur more frequently that do ranges close to the absolute minimum. 80 sets of computer output data are being delivered separately to the ATR and are not included herein. Eight additional runs were made for the four missions that are to be tracked by TDRSS. Available TDRSS epemerides, beginning at epoch 971202, were used for these runs and two-body internal ephemeris generation in ACQSCAN was employed for the target satellite ephemerides, as before. The node was selected to place either perigee or apogee at the equator, with longitude equal to 80 degrees. This places these positions in the orbit close to the middle of the TDRSS zone of exclusion, where a satellite is not visible by either TDRSS. The initial conditions for these runs are presented in Table 14.

TABLE B-1. ORBIT PARAMETERS FOR 13 EXPANDABLE EXPLORER SATELLITE EXPERIMENTS

Experiment	Perigee (km)	Apogee (km)	i	e	Period
IMAGE	19200	64000	90	0.466879	29.05 hrs
MICRO EXPL	350	1500	57	0.078733	103.5 min
AEROS	400	2000	90	0.091168	111.6 min
ACE	252000	252000	28	0.0	15.13 days
QUASAT	18900	33159.5	63	0.220	21.12 hrs
LUSTER	384000	384000	95	0.0	28.09 days
MULTIPROBE	500	15000	90	0.51316	4.64 hrs
ARTBE	1000	13000	90	0.448493	4.28 hrs
SPEX	500	500	28.5	0.0	94.62 min
ASTRO/ATMOS	500	500	97.5	0.0	94.62 min
SAMEX	2150	2150	106.0	0.0	130.62 min
HEASI	600	600	28.5	0.0	96.69 min
HXSIE	700	700	28.0	0.0	98.77 min

TABLE B-2. ELEVATION MASK FOR WALLOPS ISLAND TRACKING STATION

TRACKING STATION DATA # 1---STATION FILE

STATION ACRONYM = WPSA
LAT = 37.927 (DEG +N) LON = 284.525 (DEG +E) ALT = -40.6570 (M)
MASK MAX ELV = 13.200 (DEG) MASK AVG ELV = 4.545 (DEG)

MASKING DATA---TERRAIN MASK

AZIMUTH	ELEVATION
0.000	6.000
25.500	6.000
28.700	2.200
33.200	5.000
37.400	1.900
78.000	0.600
85.000	8.900
90.000	11.000
95.000	8.900
100.000	2.100
143.200	2.800
148.000	1.400
152.300	2.000
160.000	2.200
163.000	1.600
213.600	1.400
216.600	2.000
228.900	3.400
230.500	9.700
235.500	9.000
235.900	4.400
259.100	6.100
266.000	12.300
270.000	13.000
274.000	12.300
281.600	4.800
290.000	4.000
290.100	8.000
291.400	8.000
291.700	4.600
310.500	6.200
310.900	10.000
328.500	10.000
335.000	13.200
335.500	6.000
360.000	6.000

TABLE B-3. ELEVATION MASK FOR GOLDSTONE TRACKING STATION

TRACKING STATION DATA # 2---STATION FILE

STATION ACRONYM = DS16
LAT = 35.342 (DEG +N) LON = 243.126 (DEG +E) ALT = 919.2080 (M)
MASK MAX ELV = 14.700 (DEG) MASK AVG ELV = 5.040 (DEG)

MASKING DATA---TERRAIN MASK

AZIMUTH	ELEVATION
0.000	4.200
25.000	3.700
47.400	3.000
63.700	3.600
76.400	5.000
77.300	7.500
80.500	11.500
84.900	14.000
90.000	14.700
95.100	14.000
99.500	11.500
102.700	7.500
103.700	4.300
124.500	5.600
138.800	3.900
146.000	4.900
153.500	5.000
162.000	4.100
179.100	4.200
210.000	3.600
231.100	3.100
242.000	3.600
251.700	2.600
255.500	1.900
257.300	7.600
260.500	11.500
264.900	14.000
270.000	14.700
275.100	14.000
279.500	11.500
282.700	7.500
284.300	2.600
297.100	3.000
298.700	2.300
330.000	3.600
360.000	4.200

TABLE B-4. ELEVATION MASK FOR ALASKA TRACKING STATION

TRACKING STATION DATA # 3---STATION FILE

STATION ACRONYM = ULAE
LAT = 64.977 (DEG +N) LON = 212.482 (DEG +E) ALT = 298.3900 (M)
MASK MAX ELV = 19.000 (DEG) MASK AVG ELV = 8.759 (DEG)

MASKING DATA---TERRAIN MASK

AZIMUTH	ELEVATION
0.000	15.600
10.000	14.000
20.000	10.500
28.000	8.500
31.000	8.900
35.000	8.600
40.000	6.000
47.000	7.600
54.000	7.600
70.000	5.000
95.000	5.000
100.000	6.000
130.000	9.000
135.000	10.000
140.000	10.000
145.000	9.000
162.000	14.800
166.000	16.400
168.000	16.800
176.000	18.500
180.000	19.000
184.000	18.500
192.000	16.800
194.000	16.400
198.000	14.800
205.000	12.100
216.000	7.800
220.000	7.400
235.000	5.000
325.000	5.000
330.000	6.000
334.000	8.500
345.000	12.000
352.000	14.400
356.000	15.100
360.000	15.600

TABLE B-5. ELEVATION MASK FOR CANBERRA TRACKING STATION

TRACKING STATION DATA # 4---STATION FILE

STATION ACRONYM = DS46
LAT = -35.405 (DEG +N)   LON = 148.983 (DEG +E)   ALT = 664.2710 (M)
MASK MAX ELV = 15.000 (DEG)   MASK AVG ELV = 5.793 (DEG)

MASKING DATA---TERRAIN MASK

AZIMUTH	ELEVATION
0.000	2.500
35.000	8.200
50.000	8.400
65.000	9.900
78.400	10.200
82.400	13.500
85.000	15.000
95.000	15.000
97.600	13.500
105.000	6.800
110.000	7.600
115.000	7.500
130.000	4.000
160.000	1.900
165.000	2.800
170.000	1.900
195.000	3.700
208.000	3.600
223.000	2.900
234.000	3.900
240.000	2.500
254.000	5.200
262.400	13.500
265.000	15.000
275.000	15.000
277.600	13.500
286.000	4.500
295.000	3.500
300.000	2.000
317.000	3.000
323.000	1.000
324.000	8.000
332.000	8.000
333.000	1.000
355.000	2.500
360.000	2.500

TABLE B-6. ELEVATION MASK FOR MADRID TRACKING STATION

TRACKING STATION DATA # 5---STATION FILE

STATION ACRONYM = DS66
LAT = 40.430 (DEG +N)   LON = 355.749 (DEG +E)   ALT = 821.1710 (M)
MASK MAX ELV = 18.000 (DEG)   MASK AVG ELV = 9.467 (DEG)

MASKING DATA---TERRAIN MASK

AZIMUTH	ELEVATION
0.000	12.000
2.500	12.400
16.700	12.000
30.100	14.000
35.000	14.000
39.700	11.600
48.000	10.000
65.600	8.500
75.800	7.500
77.900	10.000
80.800	13.000
86.700	15.400
93.300	15.400
98.400	13.400
102.100	10.000
105.200	4.000
130.000	4.600
167.700	6.000
190.800	6.000
210.000	4.300
236.700	7.000
250.000	7.500
254.600	8.000
256.700	10.000
262.000	14.000
265.800	15.400
274.200	15.400
278.000	14.000
281.800	11.000
285.000	8.000
303.500	10.000
320.000	14.000
328.800	18.000
331.600	17.800
345.000	14.000
360.000	12.000

TABLE B-7. SLANT RANGE TO SATELLITE AT APOGEE FROM THE WALLOPS TRACKER; ELEVATION ANGLE = 0, AND MIN, AVG, AND MAX FROM THE TERRAIN MASK

Experiment	Maximum possible range from WPSA, km			
	Elev = 0	Min Elev	Avg Elev	Max Elev
IMAGE	70089	70023	69586	68650
MICRO EXPL	4635	4569	4158	3404
AEROS	5442	5376	4961	4178
ACE	258300	258233	257795	256849
QUASAT	35369	35302	34868	33944
LUSTER	390326	390260	389822	388874
MULTIPROBE	20407	20340	19909	19004
ARTBE	18301	18235	17803	16904
SPEX	2594	2529	2138	1520
ASTRO/ATMOS	2594	2529	2138	1520
SAMEX	5670	5604	5188	4399
HEASI	2849	2783	2389	1744
HXSIE	3086	3019	2622	1957

TABLE B-8. SLANT RANGE TO SATELLITE AT APOGEE FROM THE GOLDSTONE TRACKER; ELEVATION ANGLE = 0, AND MIN, AVG, AND MAX FROM THE TERRAIN MASK

Experiment	Maximum possible range from Goldstone, km			
	Elev = 0	Min Elev	Avg Elev	Max Elev
IMAGE	70089	69878	69531	68491
MICRO EXPL	4632	4425	4105	3289
AEROS	5439	5232	4908	4057
ACE	258300	258088	257740	256687
QUASAT	35369	35158	34813	33788
LUSTER	390326	390115	389767	388712
MULTIPROBE	20406	20196	19854	18853
ARTBE	18300	18090	17749	16754
SPEX	2588	2385	2088	1434
ASTRO/ATMOS	2588	2385	2088	1434
SAMEX	5667	5460	5135	4276
HEASI	2843	2639	2337	1653
HXSIE	3080	2876	2571	1862

TABLE B-9. SLANT RANGE TO SATELLITE AT APOGEE FROM THE CANBERRA TRACKER; ELEVATION ANGLE = 0, AND MIN, AVG, AND MAX FROM THE TERRAIN MASK

Experiment	Maximum possible range from Canberra, km			
	Elev = 0	Min Elev	Avg Elev	Max Elev
IMAGE	70089	69978	69449	68459
MICRO EXPL	4632	4522	4033	3267
AEROS	5439	5329	4834	4034
ACE	258300	258188	257657	256655
QUASAT	35369	35258	34731	33758
LUSTER	390326	390215	389683	388680
MULTIPROBE	20406	20295	19773	18823
ARTBE	18300	18189	17668	16725
SPEX	2588	2479	2023	1419
ASTRO/ATMOS	2588	2479	2023	1419
SAMEX	5667	5557	5060	4253
HEASI	2843	2734	2272	1637
HXSIE	3080	2971	2503	1845

TABLE B-10. SLANT RANGE TO SATELLITE AT APOGEE FROM THE ALASKA TRACKER; ELEVATION ANGLE = 0, AND MIN, AVG, AND MAX FROM THE TERRAIN MASK

Experiment	Maximum possible range from Alaska, km			
	Elev = 0	Min Elev	Avg Elev	Max Elev
IMAGE	70090	69538	69128	68050
MICRO EXPL	4648	4126	3779	3017
AEROS	5452	4926	4569	3761
ACE	258300	257746	257333	256237
QUASAT	35371	34821	34415	33360
LUSTER	390326	389772	389359	388261
MULTIPROBE	20410	19863	19464	18444
ARTBE	18304	17758	17361	16725
SPEX	2616	2120	1821	1266
ASTRO/ATMOS	2616	2120	1821	1266
SAMEX	5680	5152	4794	3975
HEASI	2869	2367	2059	1467
HXSIE	3104	2599	2283	1661

TABLE B-11 SLANT RANGE TO SATELLITE AT APOGEE FROM THE MADRID TRACKER; ELEVATION ANGLE = 0, AND MIN, AVG, AND MAX FROM THE TERRAIN MASK

Experiment	Maximum possible range from Madrid, km			
	Elev = 0	Min Elev	Avg Elev	Max Elev
IMAGE	70089	69646	69049	68148
MICRO EXPL	4634	4211	3704	3067
AEROS	5441	5015	4493	3818
ACE	258300	257856	257254	256338
QUASAT	35369	34927	34337	33455
LUSTER	390326	389882	389280	388362
MULTIPROBE	20407	19967	19386	18533
ARTBE	18301	17862	17283	16438
SPEX	2593	2186	1748	1286
ASTRO/ATMOS	2593	2186	1748	1286
SAMEX	5669	5242	4718	4033
HEASI	2847	2437	1986	1493
HXSIE	3084	2672	2210	1690

TABLE B-12. MAX RANGES FROM TDRSS TO TARGET SATELLITES

Sat I.D.	R_1, (km)	R_2, (km)
MICRO EXPL	46224.57	-------
AEROS	47054.30	-------
MULTIPROBE	62114.39	48954.63
ARTBE	60004.64	44178.21

Notes: R_1 applies when H = 100 km
R_2 applies when H = 12000 km

TABLE B-13 ORBITAL ELEMENTS USED FOR ACQSCAN COMPUTER RUNS

SAT I.D	a	e	i	Asc Node	Perig.
IMAGE	47978.14	0.466879	90.0	353.031 83.031	0, 90, 270 90, 270
MICRO EXPL	7303.14	0.078733	57.0	315.493 45.493	0, 90, 270 90, 270
AEROS	7678.14	0.091168	90.0	341.297 71.297	0, 90, 270 90, 270
ACE	258378.14	0.0	28.0		
QUASAT	32407.87	0.22	63.0	335.717 65.717	0, 90, 270 90, 270
LUSTER *			95.0		
MULTIPROBE	14128.14	0.513160	90.0	340.316 70.316	0, 90, 270 90, 270
ARTBE	13378.14	0.448493	90.0	341.231 71.231	0, 90, 270 90, 270
SPEX	6878.14	0.0	28.5	304.404 34.404	0 0, (MA=90)
ASTRO/ATMOS	6878.14	0.0	97.5	346.980 76.980	0 0, (MA=90)
SAMEX	8528.14	0.0	106.0	353.583 83.583	0 0, (MA=90)
HEASI	6978.14	0.0	28.5	304.513 34.513	0 0, (MA=90)
HXSIE	7078.14	0.0	28.0	304.653 34.653	0 0, (MA=90)

TABLE B-14 ORBITAL ELEMENTS USED FOR ACQSCAN COMPUTER RUNS WITH TDRSS TRACKING

SAT I.D	a	e	i	Asc Node	Perig.
MICRO EXPL	7303.14	0.078733	57.0	163.436	0, 180
AEROS	7678.14	0.091168	90.0	164.230	0, 180
MULTIPROBE	14128.14	0.513160	90.0	185.025	0, 180
ARTBE	13378.14	0.448493	90.0	182.321	0, 180

APPENDIX C : LINK CALCULATION

APPENDIX C - LINK CALCULATION

The power received in an antenna communication system is given by

$$Pr = Pt\ Gt\ L\ Gr, \qquad \text{(C-1) [Ref. 11]}$$

where,

- Pt = power into transmitter antenna
- Pr = power out of receiver antenna
- Gt = gain of transmitter antenna
- Gr = gain of receiver antenna, and
- L = loss factor of space link, including margin.

The receiver power per bit must provide an adequate signal compared to the thermal noise:

$$Eb/No = (Pr/Dp)/kT \qquad \text{(C-2)}$$

where,

- Eb/No = ratio of bit energy to thermal noise spectral density
- Dp = playback data rate
- k = Boltzmann's constant = 1.38×10^{-23} J/degK (Joule per degree Kelvin), and
- T = effective receiver temperature.

The Eb/No ratio is related to the data encoding method and the Bit Error Rate (BER). A typical choice is coherent Phase Shift Keying (PSK) and a BER of 10^{-5}, which implies an Eb/No ratio of 9.6 dB [Ref. 12]. The playback data rate achievable with a specified transmitter power may then be computed from

$$Dp = (Pt\ Gt\ Gr\ L)/(Eb/No)kT = 218.7 \text{ dB degK/J EIRP G/T L} \qquad \text{(C-3)}$$

where,

- EIRP = Effective Isotropic Radiated Power = Pt Gt, and
- G/T = Gr/T = ratio of receiver gain to system thermal noise temperature.

The parameters EIRP, G/T, and L on the right of (C-3) are each discussed below.

TDRSS normal-power EIRPs for the MA, and SSA channels are shown in Table C-1 [Ref. 3]. A ground transmitter has effectively unlimited EIRP. The spacecraft EIRP is the product Pt Gt. The TDRS and near-Earth spacecraft transponders each provide an antenna power of Pt = 5 Watts. The spacecraft transmitter gain Gt will depend on the choice of antenna; a variety will be considered for Space Network communication. For communication to a ground station it is usually adequate to use an omnidirectional antenna with Gt = 1 = 0 dB.

Effective G/T ratios for the SMA and SSA channels are shown in Table C-1 [Ref. 3]. The gains Gt or Gr of antennas used on an EES or the ground may be computed from

$$G = 4\,pi\ \{(A\ e)/(lambda)^2\} \qquad \text{(C-4)}$$

where,

- A = antenna area
- e = radiation efficiency, typically 54% for dishes, 70% for planar arrays, and
- lambda = wavelength.

The MA center frequency is 2288 MHz, for which the wavelength is 0.13 meter. This may also be taken as typical for the SSA channel range of 2200 to 2300 MHz and for S-Band ground station communication. The ground antennas considered are 6, and 9 meters in diameter. For uncooled receiver systems, T may be assumed to be approximately 300 degK. The G/T ratios for these ground antennas are shown in Table C-2.

For ground communication L may be computed from

$$L = Lp\ M\ (\text{lambda}/4\ \text{pi}\ r)^2, \qquad \text{(C-5)}$$

where,

Lp = polarization, pointing, other losses, typically -3 dB,
M = margin, typically -3 dB, and
r = transmitter-receiver range, given by Appendix B.

Table C-1. Space Network Communication Parameters

Parameter	TDRSS channel SMA	SSA
EIRP	34 dBW	43.6 dBW
G/T	-1.9 dB/degK	9.2 dB/degK

Table C-2. Ground Station Communication Parameters

Parameter	Ground antenna diameter 6 meter	9 meter
EIRP	unlimited	unlimited
G/T	16.2 dB/degK	19.7 dB/degK

APPENDIX D: ACHIEVABLE DATA RATE

APPENDIX - D ACHIEVABLE DATA RATE

To satisfy the strawman experiment requirements, different data rates are needed to transmit science data to the ground data processing system via ground stations or TDRSS. Factors in determining what data rate is needed for what strawman instrument are:

a) average instrument data rate,

b) number of contacts per day between the spacecraft and the receiving station and,

c) the average useable contact time.

Equation D-1 produces a first approximation for the transmission data rate required to satisfy the individual strawman experiments and was used to plot the strawman experiments on the graphs in figures 7 - 1 through 7 - 4.

$$TDR = ((1000*AIDR)*86400 \text{ sec./day}) / (CPD) / ((AVT - 2.5 \text{ min.})*60) \qquad (D - 1)$$

where, TDR = transmission data rate,

AIDR = average instrument data rate in kbps,

CPD = contacts per day and,

AVT = average viewing time.in minutes.

To produce this first approximation the following assumptions were made. First, it was assumed the average data rate listed in Table 3.3-2 was the average data rate for that experiment for a day, (AIDR is multiplied by 1000 to get it in terms of bit per second). Second, it was assumed that the tape recorder was able to play back data at a rate different than at which it was recorded. Third, the CPD were taken as the average number of contacts per day as determined from the tables in Appendix A. Depending on the average view time, when an individual view period was three to five minutes shorter than the average, it was not included in the average. Thus, view periods that were to short to be useful for returning science data were not averaged in. These periods could still be used for commanding. Fourth, two and a half minutes was subtracted from the average view time (and multiplied by 60 to get it in terms of seconds) before it was divided into the equation. Fifth, it is assumed that when TDRSS is used there will be four regularly scheduled contacts per day about six hours apart and with each contact lasting about 20 minutes. Sixth, it was assumed that the ground station would be dedicated to the EES mission during the entire view period of a spacecraft pass. This may or may not be true for spacecraft with long orbital periods.

The TDRs were then plotted against maximum slant range, as determined in Appendix B, in Figures 7 - 1 through 7 - 4 for a trade off study between TDRSS and ground stations and to check the performance of the designs presented by the EES Study Team [Ref. 2].